NTIAC 74-1

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PROCEEDINGS OF THE 1973 SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

Editor: PAUL E. J. VOGEL

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Part 1 of 4

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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. AD-A094 451	2.	3. Recipient's Accession No.
4. Title and Subtitle	Proceedings of Four Symposia on Nondestructive Testing of Tires.		5. Report Date 4/73, 10/74, 1/76, 5/78
			6. 25 May 78
7. Author(s)	Paul E. J. Vogel		8. Performing Organization Rept. No. NTIAC 74-1, 75-1; AMMRC SP-78-2; SP-80-1
9. Performing Organization Name and Address	Army Materials and Mechanics Research Center Nondestructive Evaluation Branch Watertown, Massachusetts 02172 NTIAC-74-1, NTIAC-75-1		10. Project/Task/Work Unit No. M6350; 53970M6350
			11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address	Army Materials and Mechanics Research Center Materials Testing Technology Division Watertown, Massachusetts 02172 AMMRC, AMMRC SP-78-2, SP-80-1		13. Type of Report & Period Covered: Proceedings of Symposia 1974-1978
			14.

15. Supplementary Notes Proceedings of Symposia held in Boston, MA, April 1973; Atlanta, GA, October 1974; Akron, OH, January 1976; and Buffalo, NY, May, 1978.

16. Abstract (Limit: 200 words) This four-volume hard-cover set of Symposium Proceedings devoted to Nondestructive Testing of Tires contains the greatest concentration of information on NDT of Tires in the world. Sponsored by the Army Materials and Mechanics Research Center, Watertown, MA, these symposia were held in April 1973, October 1974, January 1976, and May 1978. Each symposia was composed of a general session where papers of general NDT methods were given followed by sessions specializing in the pertinent NDT methods such as radiography, ultrasonics, holography and infrared.

17. Document Analysis a. Descriptors Nondestructive Testing
Tires
Rubber
Radiography, Ultrasonics, Holography, Infrared

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 14) Methods and Equipment; 20) Physics

18. Availability Statement:	19. Security Class (This Report) Unclassified	21. No. of Pages 664
Release Unlimited	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

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21. Number of pages. Insert the total number of pages, including introductory pages, but excluding distribution list, if any.
22. Price. Enter price in paper copy (PC) and/or microfiche (MF) if known.

PROCEEDINGS OF THE 1973 SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

Editor
PAUL E. J. VOGEL
Materials Manufacturing & Testing Technology Division
Army Materials and Mechanics Research Center

10-12 April 1973

Parker House, Boston, Mass.

Sponsored by
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

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This document was published by the Department of Defense Nondestructive Testing Information Analysis Center (NTIAC), Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172. NTIAC's Mission is the collection, maintenance, and dissemination of information in the field of Nondestructive Testing.

OPENING SESSION SPEAKERS
(left to right)

Richard D. Meyer, Assistant to the President, Firestone Tire & Rubber Company, Akron, Ohio; Dr. A. E. Gorum, Director, Army Materials and Mechanics Research Center, Watertown, Massachusetts; Dr. Ernest N. Petrick, Chief Scientist, U. S. Army Tank-Automotive Command, Warren, Michigan; Lester G. Jones, Teledyne Continental Motors, Warren, Michigan; Paul E. J. Vogel, Army Materials and Mechanics Research Center, Watertown, Massachusetts, Program Chairman.

PREFACE

For the year prior to this First Symposium on Nondestructive Testing of Tires, a survey on the subject was conducted by the Army Materials and Mechanics Research Center, which is the Army's lead laboratory for materials research. The survey took us into the plants and laboratories of most major new tire manufacturers and tire rebuilders in the United States and Europe, as well as to test tracks, test equipment manufacturers, and military and other Government installations concerned with tires, regardless of type.

A vast amount of information was acquired and an effort is being made by the Center to share this information by means of a survey report that is now being published* and by discussions with interested groups.

Possibly the greatest benefit derived from the survey was the opportunity to meet the most knowledgeable people in the tire industry and to learn from them their experiences with nondestructive testing. Many of the attendees at the symposium were people we met in our travels, and they made the meeting a most impressive gathering of tire testing experts. They all participated actively in discussions from the floor and in the working groups, and obviously each could have given an interesting talk on his work. A roster of attendees is included as Appendix A.

The fifteen papers that were presented were selected to provide the best total view of the subject in the time that was available. The distinguished keynoters established the theme for the meeting with Dr. Petrick giving a fine summary of Government – particularly Army – activity in nondestructive testing (NDT) of tires and detailing the size of the DOD and Army tire procurement volume. General Meyer, speaking for the tire industry, gave very practical guidance in regard to the human, economic, and technological limiting factors that must be considered in striving for the ultimate in quality assurance.

Dr. Ginsberg, Dr. Grant, Mr. McConnell, Mr. Neuhaus, and Mr. Fiorille were particularly helpful in planning and running the symposium. Through their individual and combined efforts they brought in the excellent speakers that we heard, and they also served as an informal papers review committee to assure that all papers emphasized the work for which the symposium was designed. Lastly, they served very ably as session chairmen in their individual disciplines, and they burned the midnight oil to bring you their session summaries on the last morning.

In the preparation of this Proceedings, I have deleted very little – mostly my administrative announcements and my "city greeter" welcome and guidance. Possibly you will find a few of the questions and comments to be extraneous, redundant, and generally deserving of omission, but we have included them anyway. Our reason for this is that they will have some value to those who made them, and they will also serve as an introduction to the responses that were made. Our problem in a few instances was that the tape just could not be interpreted and transcribed, but what we could understand is included herein.

In planning for a follow-on meeting, we remembered General Meyer's remarks about having "a scientific paper which will appear in some journal of limited distribution and which will answer with great precision questions which no one will ever ask." With this in mind, it was decided that the magic word "annual" would be ignored and that the next meeting would be planned for sometime after the Proceedings have been published and digested, and when people have gone home and made advances in tire NDT and reduced their work to practice or writing. In other words, when we can find or you can produce enough *new* material to make it worth your while to come to a symposium, we will hold it. You have already voted for Atlanta, and we are tentatively aiming for a date in the Fall of 1974.

Appreciation is expressed to the American Ordnance Association and Mrs. Vogel for their assistance in the symposium.

Paul E. J. Vogel

*Vogel, P.E.J., *The State of the Art of Nondestructive Testing of Tires*, Army Materials and Mechanics Research Center, PTR 73-9, October 1973.

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11 April 1973

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12 April 1973

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CHAPTER I — OPENING OF THE SYMPOSIUM

CONVENE MEETING

Lester G. Jones
Teledyne Continental Motors
Warren, Michigan
Chairman, American Ordnance Association
Quality and Reliability Division

It is indeed a pleasure to be selected to convene this important symposium. A more interesting and, I am sure, interested audience I have not seen.

The subject of the symposium is very important and most timely to this era of austere budgets, for to be able to test a device or material to insure its proper function in use without destroying it, is indeed a welcome advantage. It's very disheartening indeed to spend a year or more to prove the reliability of a track pad for a tank, and then the very first set put into field use experiences blowouts. A nondestructive test method could discover the deficiency before these production failures. You're going to be treated for the next two days to an august group of speakers, each with an important message to bring to you.

I, too, have been charged with the responsibility to bring an important message to you. The American Ordnance Association, founded in 1919 and made up of American citizens, dedicated to peace through preparedness, wants you as member. If you believe in these principles and have a desire to remain informed on the defense posture of your country, you probably already are a member. If you are not, you will find membership blanks available at the registration desk.

As the one national professional society with a major concern for new defense armament, AOA is uniquely equipped to act as a consultant in a communications capacity on matters of Ordnance and related equipment. AOA's work is supported by some 40,000 individual and corporate members through a network of chapters, meetings, seminars, and weapons demonstrations. In various publications, such as *Ordnance Magazine*, they are the voice for preparedness for defense throughout the nation. If you are not now a member of this fine organization, may I encourage you to complete one of the application forms, mail it in, or give it to any other member. You will find a warm and beneficial welcome in this organization.

Now it is my pleasure to introduce the first speaker, Dr. Alvin Gorum.

OPENING REMARKS

Dr. A. E. Gorum, Director
Army Materials and Mechanics Research Center
Watertown, Massachusetts

It's a great pleasure to meet you here this morning. Welcome to Boston. It's gratifying to note the broad area of tire technology that is represented in this gathering – new tire manufacturers, tire rebuilders, nondestructive testing equipment manufacturers, independent test laboratories, Government safety agencies, and the major Government users of new and rebuilt tires of all types. We are gathered for a common purpose – to explore the many facets of the art of nondestructive testing as applied to tires in the interest of increased reliability, lower testing costs, and, possibly most important of all, user safety. At the Army Materials and Mechanics Research Center (AMMRC), we pride ourselves on the years of expertise that are represented in our nondestructive testing activity. Since the days when Dr. Horace Hardy Lester pioneered in industrial radiography at what was then the Watertown Arsenal, our scientists and engineers have made many advances which, while primarily oriented toward military application, have also been of great benefit to the civilian community.

The Research Center is the lead laboratory for materials testing technology for the Army Materiel Command (AMC). (The lead laboratory is a new concept that has come out in the last year or so.) We have also been designated lead laboratory for two other fields, materials and solid mechanics. As such, the Center manages and directs the research and engineering concerned with the development and application of all types of testing techniques, both destructive and nondestructive, for the evaluation of materials characteristics for research and development, quality assurance including surveillance, and field maintenance. In performing this mission, AMMRC advises and assists the major subordinate commands of AMC and the project managers in the utilization of materials testing technology. Thus, in tire work, for example, we relate closely to the Tank-Automotive Command, the Mobility Equipment Command, and the Aviation Systems Command (AVSCOM). AVSCOM, in turn, is a signator to the charter of the Tri-Department Aircraft Tire Coordination Group. It is through this close working relationship with these other Army activities, as well as the other services, that we come to be hosting this symposium.

As part of the materials testing technology program, AMMRC recently concluded an extensive study of nondestructive testing (NDT) techniques that are being applied to new and rebuilt tires. Visits were made to factories, test tracks and major purchasers in the United States and Europe. The survey revealed a great interest in NDT and a real need for versatile test equipment at reasonable cost. It also showed a surprisingly limited application of NDT in view of the current advances in the art of the major techniques.

This meeting will hopefully provide an in-depth exchange of ideas that will ultimately lead to the best possible quality in tires at the lowest possible cost. We are here to serve you, and if you have any requirements please feel free to call on any of our people who are present. Thank you very much.

CHAPTER II – KEYNOTE SESSION

KEYNOTE ADDRESS (Government)

Dr. Ernest N. Petrick, Chief Scientist
U. S. Army Tank-Automotive Command
Warren, Michigan

Good morning, gentlemen. I am pleased to be invited to be one of your keynote speakers. I am particularly pleased because I listened to the news this morning and saw the weather I left out in the Midwest, and I'm not looking forward to going back, although I understand it may be just as bad here today, but we'll see.

We have here today various segments of industry and Government to participate in this symposium, and I would like to focus on at least some of the Government's interests and efforts, but you will have to recognize that I am with a purchasing and a using agency rather than with a regulatory agency; therefore, my comments are going to be influenced toward the needs of the user. But all segments of Government and industry have a mutual interest with regard to promulgating effective nondestructive testing methods for tires. Although Government purchasing is not nearly as large as purchasing by the major automotive and truck companies, statistics do indicate that Government is the largest tire user in the country, and of those I'm sure that the Army is the largest fleet user. Under the centralized procurement system which was set up several years ago, the Army buys nearly all the general purpose ground vehicles and the replacement tires for the Department of Defense (DOD). In Fiscal Year 1972, the acquisition for DOD totalled one million tires of which some 700,000 were military types and 300,000 commercials. The General Services Administration (GSA) buys most of the tires for Government civilian services, and these totalled about 585,000 tires. The Navy and the Air Force in a typical year buy about 280,000 tires for aircraft usage. So the total Government purchase is thus some two million tires per year at a total cost of some 70 million dollars. I believe last month was the biggest automobile sales month in years, and I think there were one million vehicles sold, so you can see that the two million total annual tire buy by the Government is pretty small compared to the monthly buy by industry, but it is significant.

Now in regard to retreading, which is one of our significant activities, the GSA and the Army retreaded over half a million tires in 1972; the Navy and the Air Force retreaded about 80,000 aircraft tires at a cost of only about 30 percent of the cost of purchasing a new tire. These statistics are used to illustrate and emphasize the importance that the Government as a user must place on the evaluation methods to measure tire reliability, durability, and safety, both for new tires and for retreads.

With regard to the regulatory branches of the Government, we all know that we are living in an era of increasing awareness of public health and safety; the Federal Government has played a significant role in establishing uniform codes and uniform standards which serve to minimize the inconsistencies that can arise when individual States enact differing requirements. One of the forerunners in the Government safety standards was the work of the Interstate Commerce Commission in regulating various modes of transportation equipment and cargoes. In recent years Government agencies have been directed by Congress and by the Administration to develop time-phased controls on motor vehicle safety measures, including tires, with regard to their reliability and durability. The Department of Transportation (DOT) and the National Highway Traffic Safety Administration (NHTSA) have been assigned the task of establishing such standards. For example, Motor Vehicle Safety Standards (MVSS) 109 is in effect for new passenger car tires requiring conformance with high speed, endurance, strength, dimensional limits, and resisting bead unseating during compliance tests. These compliance tests for high speed, endurance, and bead unseating resistance are performed under conditions specified by DOT. These tires must also have tread wear indicators around the tread to serve as an alert that replacement or retreading is necessary. In fact, a molded marking of the letters "DOT" is required on all new tires signifying conformance to MVSS 109 provisions. A proposal has been issued to take effect September 1974 to require the tire to be further labeled indicating its grade for tread wear, traction, and high performance based on these NHTSA control standards.

With regard to another standard, MVSS 117 for retreaded passenger tires is proposed to be effective in June 1973. It originally required performance characteristics similar to new tires, to be tested on an indoor test wheel. The retreading industry objected to retreads having to meet the same high speed and endurance compliance tests as new tires.

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The Circuit Court of Appeals in December 1972 set aside the wheel test requirements. I won't comment any further on this standard. Obviously there's more action to be seen in this particular arena.

Regarding new truck tires, MVSS 119 has been in preparation for several years, and its implementation is expected within the year. The provisions are somewhat similar to the provisions required for new passenger tires. A standard for retreaded truck tires has not yet been proposed and apparently is some distance still in the future.

These examples point up some of the ever-tightening controls on tires. The DOD strives to comply with such safety standards and controls, even on combat equipment when possible. In some instances, to assure tire reliability, the military services are planning to introduce nondestructive tire testing, particularly in periodic maintenance checkout on aircraft tires and in our retreading operations. For these reasons, the Government is engaged at present in developing and evaluating nondestructive test equipment and methods, both in-house and under contract.

During the course of time, the Government has acquired considerable experience with various NDT methods. I can relate some of the efforts undertaken at the Army Tank-Automotive Command which I will refer to as TACOM or the Detroit Arsenal. (We still have a little segment that we refer to as the Detroit Arsenal.) I'm going to outline those efforts later, but we in Government as well as in industry still conduct destructive tests on the road and on indoor wheel dynamometers, followed by sectioning and evaluation. We believe that there will be a need to continue this for two reasons: first, because there are physical properties and tire characteristics which cannot as yet be evaluated by nondestructive means (we hope to find out more about that during this symposium); secondly, to obtain correlation data for the purpose of establishing nondestructive test procedures and establishing flaw standards. There are, however, numerous advantages associated with NDT methods for detecting and measuring latent flaws which could obviate or at least reduce the need for longtime dynamometer wheel tests. In a wheel test, if failure is catastrophic, as many of you know analysis for cause of failure is extremely difficult. Even the tires which do not fail are no longer considered serviceable since they have been subjected to some extremely severe test conditions. This highlights one of the plus advantages of nondestructive testing. Since the test tires are unaffected by NDT examination, they are completely serviceable with the exception of those which have rejectable defects. However, in order to establish acceptable flaw limits for nondestructive examination requirements, some serviceable tires will still need to be sectioned on an interim basis to achieve confidence in the method. A tire which is destructively inspected on a routine production sampling basis is a total loss; therefore, the quantity tested is understandably low. NDT will permit a higher volume of tires to be examined. This volume will increase as the art advances and the equipment becomes more discerning, measures more characteristics, becomes lower priced, and reduces the inspection time.

The Army, for example, has a goal of performing 100 percent NDT inspection of ground vehicle tires before and after retreading operations. The Navy and the Air Force have similar objectives for retreaded aircraft tires. We must be concerned with the safety of the personnel and with the combat readiness of the military equipment. Furthermore, we believe that ultimately there will be a cost saving from NDT by detecting worn casings with internal flaws not normally found by visual inspection or during buffing. We also wish to be assured that the retreading does not introduce an additional deficiency, such as poor adhesion, which could lead to separations between the casing and the new tread.

I don't intend to discuss in any detail the NDT methods or the many variations that have been explored or are now in use or under development. These will be very capably and thoroughly described by later speakers who are experts in their fields. I merely wish to comment on those methods that have been studied and applied to some degree by the Government agencies.

At least three methods of utilizing X-rays have been investigated and used. These are film radiography, xeroradiography and fluoroscopy. Film radiography is the oldest and is similar to the approach still widely used for diagnosis of the human body and for industrial components. It is also the most expensive in time and materials and is, therefore, now used mainly for confirmatory purpose. Xeroradiography employs an electrostatically charged plate and provides either a film or a processed paper facsimile. Fluoroscopy, which originally involved direct viewing on a screen fluoresced by high energy X-rays, now has been sophisticated to the extent that lower voltage X-rays can be used, converted to light, intensified, and viewed remotely on a television screen. Infrared examination produces scanned images or trace recordings of thermal radiation in a tire during its operation. These have been studied in wheel tests and on the road. Holography, a new science, employs a double-exposure technique of a tire in the stressed and the unstressed states, and the resulting stress patterns which deviate from the normal pattern indicate the presence of anomalies which have to be investigated. Ultrasound has had numerous applications in tire testing techniques. Although there are many variations in frequencies, transducers and instrumentations, the modes generally can be categorized as pulse echo, through-transmission and resonance. The resonance method appears still to be somewhat in the research and development stage. I expect that

other NDT approaches have been studied for tire evaluation, but the ones mentioned are the most widely investigated and applied. Surveys are continually ongoing by the Tri-Service Nondestructive Inspection Committee of the Tire Coordinating Group and, as we heard, by the Army Materials and Mechanics Research Center. These are the developments I am sure we're going to hear about in the next two days.

Let me quickly summarize the Government's activities in NDT on tires, both internal and on contracts. First let me review the Army activity with which I'm most familiar. As early as 1955 the Detroit Arsenal evaluated a Goodyear ultrasonic tire tester developed for screening worn tires prior to retreading. It employed a through-transmission liquid-coupled principle. In 1958 Detroit Arsenal and Frankford Arsenal collaborated in a project to develop ultrasonic equipment for 7.00x16 size military tires with some variations from the previous Goodyear unit. The technique also involved immersion, through-transmission and amplitude attenuation principles. In 1958 and later, xeroradiography was investigated. It was found to be reasonably satisfactory, but the lengthy time element in examining a tire precluded its routine application. In the late 1960's, Army Materials and Mechanics Research Center investigated infrared methods of examining tires. Because infrared requires dynamic operation of a tire with a simulated load in the laboratory, a dynamometer was improvised locally. Later, from 1970 to 1972, taking advantage of the larger wheel test equipment at TACOM, infrared diagnoses were conducted both on test wheels and in highway operations. These tests were performed to determine temperature gradients, failure potential, correlation of wheel versus road data, effects of ambient conditions and the effects of road surfaces on tire temperatures; these data are available in technical reports.

Today the Army has just initiated parallel and competing contractual development of ultrasonic pulse-echo and ultrasonic air-coupled through-transmission systems for potential use in the military tire retread program. Since Army military tires have heavy tread lugs which complicate ultrasonic signal amplitude and pulse reflection, special methods are required to compensate for the thickness variations. In the course of this program, film radiography and holography will be used for confirmatory testing. Although the Navy and the Air Force have evaluated various methods, their efforts are concentrated on ultrasonics at present. The Air Force has contracted for development tasks on high frequency pulse-echo and the low frequency air-coupled through-transmission systems. The Navy is performing in-house development of a pulse-echo equipment system. The National Bureau of Standards has in the past investigated the nondestructive methods of tire testing, particularly in ultrasonics and infrared. More recently, the Safety Systems Laboratory and the Transportation Systems Center of the DOT have accounted for most of the Government activity in the NDT field outside of the DOD. I'm sure many of these activities are going to be reviewed in this symposium.

Based on these various activities, let me note in closing some of the needs as we see them now. I mentioned earlier the Army's current emphasis on evaluating ultrasonic methods for application in the tire retread program. This is not meant to imply that other NDT methods were found to be unsatisfactory. But Army forces are widely dispersed over the world and often are remote from our retread facilities. Our goal is to have NDT equipment which can be located at these bases for rapid inspection of tires before shipment to retread facilities. The test unit should be of relatively low cost, reasonably rugged, mobile, hopefully with an automatic defect alarm, and requiring minimal operator training. That's really what we are looking for. For the short range, we believe that ultrasonics shows promise of meeting that objective. We do recognize that if equipment and testing costs are too high, and if the cost is added to the cost of the retread operation, it may become uneconomical for us to retread these tires. Therefore, we trust that the equipment manufacturers will consider the needs and the market for this particular type of application. Secondly, with regard to new tires, if dynamometer and road tests prove that a tire design is satisfactory, and reproducible in production with regard to its safety, reliability and handling characteristics, and if the attributes of the tire could be identified and measured by NDT means, the need for destructive testing could either be eliminated or significantly reduced. I think that's our common objective. Thus, meeting Government safety standards could be assured as well as benefits to industry by reducing the cost of such testing.

Let me close by citing a unique need which is of more concern to the military than to the other arms of Government. This is the matter of rubber degradation during aging, either in storage or on vehicles. The problem lies in the nature of our organizational structure and the widespread dispersion of our storage facilities. Units or vehicles are assigned to National Guard and military reserve units which accumulate mileage slowly and on an extremely sporadic basis. In some cases the original tires have been on vehicles as long as 15 years. Some unused tires in strategic reserve storage are as much as 10 years old. How do we know if and when they should be replaced for operational readiness? One of our long-range goals must be to devise a nondestructive method of measuring the extent of deterioration and assessing the life expectancy remaining in the tires.

Based on our experience, gentlemen, we believe that nondestructive testing of tires is approaching the application stage. The needs, as indicated by some of the examples I've cited, are real and we believe are potentially cost effective.

There will be no dearth of customers or users once the techniques and the equipment are available and are shown to be reliable. I hope that one of the accomplishments of this symposium will be to assess our status in attaining this widespread application of NDT methods for both new and retreaded tires.

KEYNOTE ADDRESS (Industry)

Richard D. Meyer, Assistant to the President
Firestone Tire & Rubber Company
Akron, Ohio

I see I'm billed as a speaker for the industry. What I have to say will have to be a very personal review. I feel I'm uniquely qualified to speak for an industry whose history goes back nearly 100 years. From my biography, you can see I'm almost that old. My own company celebrated its 73rd anniversary this year. Last fall the President of the company handed me my five-year pin saying that I was probably the oldest guy who ever won one of those pins and adding that as far as he was concerned, I was probably the last.

I intend to offer an overview, then, of a manufacturing process for which we in the industry would like to provide 100 percent instrumented and nondestructive testing. We cannot because current technology isn't there. And so I hope that this overview will point out the areas of greatest concern to the management of the industry.

We've heard a lot about testing; let's talk a little bit about the product that we're going to test. I confess that, when I entered on my apprenticeship some 5½ years ago, I had the vague notion that tires were somehow punched out of an enormous sea of raw materials, cooked in an enormous oven, and rolled into the distribution system something like doughnuts out of a doughnut machine. Nothing could be further from the truth. Tires are hand-crafted on complex machines by an artisan who dances to some mysterious tune, choreographed in mysterious symbols. The materials he handles are mixed and spun and woven and cut to size by other teams of craftsmen and machines. They are built upon cylindrical drums; they come out looking something like a barrel with neither head nor foot; and then these barrel-shaped raw tires are moved to presses where they are shaped and cured into the familiar form that you see on your car. The tire industry as a whole makes more than a half million of these every day.

Now, obviously, despite the high degree of craftsmanship of each builder, and despite rigid quality control and supervision throughout the system of handling and moving the materials in process, each tire is the sum of the work of many individuals and many processes. And yet the cured tire is a single indivisible product that cannot be reworked to remove or replace a flawed part.

My basic thesis, then, is simply this: each tire is an individual; each has its own variation from design characteristics. The only proof of its performance is its performance, and in today's technology only testing to destruction in use can tell us how any individual tire will behave in total, and, strictly speaking, it will only tell us how it did behave. If this were not so, the major tire manufacturers wouldn't have to spend literally millions of dollars operating road tests on elaborate test tracks as we all have, and the major automobile manufacturers would not have similar field test tracks to check conformance to specifications as well as the compatibility of the tires with the machines on which they are to be mounted.

One of the most important parameters, of which we've heard nothing so far and which we'd like to be able to measure on a tire, is its ability to wear. Now we do know by comparative testing that the same green tire, this barrel-shaped device I've mentioned that is placed in a different mold with a different tread design, will wear differently, sometimes as much as 50 percent. We find also that the same tire will behave differently in use.

In order to test this out, last fall we sent out a number of our new trainees, college graduates, to observe the appearance and the wear characteristics of newly mounted tires on current vehicles. We had to consider only new vehicles because we had to start out with the basic assumption that the odometer reading was the actual mileage both of the car and of the tires.

The sum total of the results of literally thousands of measurements proved what you would expect: that there is a wide variation in the wear performance achieved by any given driver depending upon where he drove, the conditions under which he handled his car, and the care he took of it, and significantly consistent measurable results correlated to environment, geographical location, maintenance, etc. For example, if you drive in Atlanta you can expect 30 percent less tire wear than you would in, say, Philadelphia. There were other findings, but the most significant finding relates to the driver. Our study led us to the conclusion that the greatest influence on the wear of tires is the driver. His

driving habits and the degree to which he gives attention to the maintenance of his vehicle and tires can affect the wear he will get to a highly significant degree, and one could almost say, orders of magnitude.

So, thus far, we have established that the real-life performance of the product to which this testing symposium is addressed can vary tire by tire in its manufacture and tire by tire in its use. In each case, manufacture or use, the supreme variant is the human being. Many mechanical processes or products whose critical component, such as the compressor of a home freezer, may be warranted, operate in a predictable environment, not affected by human operators; they are sealed and maintenance free, and they are repairable part by part. Furthermore, they are manufactured as assemblies of individually predictable standard components. The components can be tested both before and after assembly. If there is a flaw, the assembly can be replaced, or it can be reinstalled correctly.

These variations in the manufacture and use of tires are recognized in a recent publication by the National Highway Traffic and Safety Administration (NHTSA) in their long awaited final draft on tire quality, grading and labeling. I am in no position at this time to endorse that document at this symposium, but these quotations from that particular draft are pertinent: "The grade a tire is given for tread wear would be based upon its performance when compared to a control tire. NHTSA plans to sample test control tires to determine uniformity and to make availabe to manufacturers tires from uniform batches for grading tires. This is being proposed by NHTSA as a method of keeping to a minimum variations in the control tire (the test device) which can occur due to the nature of tire construction despite precise specifications." A little further on it says, "The proposed grades for tread wear represent that the tire can produce at least that percentage of the tread wear performance of the control tire. NHTSA has decided that it is impractical to provide actual mileage figures for tread wear ratings because mileage figures vary widely depending upon such factors as geographic location, environmental effects, and individual driving habits."

Now the purpose of this symposium is to examine nondestructive testing of tires, so I ask you the question: Testing for what? For quality control? Yes. During the developmental stages we can measure conformance to many design parameters with considerable accuracy, both destructively and nondestructively. We can instrument in many ways for whether the tire building craftsman deviated from specification by techniques which you will discuss here. Some of these techniques measure a visual representation of the components and how they relate to each other. Other devices measure the uniformity of tires. Now within empirical limits, these devices predict whether the radial and lateral force responses of the tire, its balance, its roundness, its vibratory periods will, in actual operation, register unacceptable G-forces on the human sensory-resources. If our product does not satisfy or does not appear to satisfy that instrument of customer satisfaction, back it comes for adjustment, and that costs money. So in addition to all the instrumentation available to us, we have highly trained individuals who inspect the finished products as they roll off the line, both visually and with other instrumentation, or to make sure with their own human senses that the tire looks and feels like a perfect product.

The rubber industry as a whole, and the individual companies, have contributed much to the science of nondestructive testing. But I reiterate that all the devices we are going to discuss in this seminar test for quality control or for latent defects, and that's all they show. In real life, most tires are run to wearout. Of those few tires which are removed before wearout, more than half are removed for cuts or snags, and another large group of that very small fraction are adjusted for vibration. Only a minimal few are replaced for latent defects. Your conference agenda leads me to the conclusion that we are giving great effort to provide nondestructive testing for latent defects, and none, here at least, to the problems we have not solved. Can we not discover a nondestructive test which can quickly affirm expected wear, perhaps by molecular loss rate in a small removed sample, or by some other physical principles? Wear is the major factor that the consumer relates to tire life and tire value. Of course, it would take a most complex machine to predict with any accuracy how any one tire would wear in use by any given customer. NHTSA admits that we must deal with the comparison of averages for, in the final analysis, statistics or measurements will only display qualitatively the characteristics which ought to give any customer the best tire that he can get for the usage he proposes and for the price that he's willing to pay.

The safety record of the American motorist is still abysmally bad. It's a matter of record that half the auto accidents involve drivers who have been drinking. And it's also a matter of record and of industry-wide pride that the proportion of accidents attributed to tires is a minute fraction of one per cent. The statistics we have don't differentiate, but other tests and observations lead us to the belief that most of the accidents attributed to tires were caused by overloading, by underinflation, or by driving at excessive speeds on worn tires; and this despite the markings on the tire which indicate wear, and specify safe loads and required pressures.

I wouldn't have you believe that there are not major and compelling reasons for the tire industry to concern itself with quality assurance. I would like to touch on two of

these reasons in addition to the normal economics of marketplace competition. First, there are undefined but considerable economic implications arising from the totally new phenomenon of product liability law. Some States have gone so far as to extend the doctrine of virtually absolute reliability to manufactured products. In the context of today's consumerism and of the generally bad press given to big corporations in particular, large jury awards for product liability suits are not infrequent. Without expanding too much further on this point, the economics of product liability are such as to warrant major capital outlays for precise quality control and meaningful quality assurance testing. The industry, in fact, checks or tests a high proportion of its production, and it inspects 100 percent of its production.

Another and perhaps more direct influence upon our testing requirements has been the imposition of Government regulations under the provisions of the National Traffic and Motor Vehicle Safety Act of 1966. The operation of that Act has been to cause an enormous increase in testing and in record-keeping, all of which is reflected in costs passed on to the consumer. Explicit in the Act also is the authority to impose such heavy penalties as fines or mandated recalls.

In summary, then, we must test nondestructively for quality control and quality assurance, for compliance with regulations, and for protection in cases of product liability.

But in response to my own question of some time ago – test for what? – I have to say that we are not testing for customer satisfaction. We cannot measure scientifically the infinite combinations of car, suspension, tires, roads, environment, usage, geographic location, individual driver maintenance, driving habits, and just plain human cussedness.

Now this symposium is aimed at the technology of measurement of the quality of manufacture of our products. There are certain characteristics which our techniques must satisfy in this competitive market. The first of these is capital outlay and increased cost of manufacturing. The industry has already made sizable capital outlays to confirm compliance with tests prescribed by Government standards and regulations, yet it cannot be documented that all of these tests relate to actual road performance. We have before us a requirement for grade labeling in which samples of our products are to be tested in real life on the road against control tires for at least 16,000 miles for each sample tested. (To operate a test car costs us about $4,000 a month. By driving full force you can run about 1,000 miles a day, 22,000 miles a month.) So you can see, with something like 400 identifiable items produced by a major manufacturer, that we desperately need a laboratory test to reduce the burden of cost to the consumer that such real-life testing entails.

The main thrust of my discussion has been the inspection of newly manufactured tires. On the subject of retreads, the inspection of carcasses for retread covered in some detail by Dr. Petrick is also highly significant in the industry. My company is deeply involved in retreading and the supply of materials to retread shops which we operate ourselves as well as to franchise shops. Firestone is probably the largest commercial retreader in the business.

In our discussions with the Department of Transportation, we've had to stress the fact that we have no reliable commercially acceptable technology with which to certify worn carcasses for retread. The advantage of retread is that it offers an extension of the life of the tire at a fraction of the first cost, and that advantage is obviously reduced by the cost of inspection equipment and the inspection effort. Each retread shop is a small business operation run very close to the vest financially. The challenge to your technology then is to come up with a simple, cheap, reliable method for inspecting and verifying the condition of the carcass to be retreaded. To continue competitively, the retread must retain its price advantage over the new tire. Retreading costs, both first cost and operating expense, must be within the reach of the small business man.

We can sum up then the most significant characteristics which must be possessed by any technology for inspection of tires, whether new or used, as follows:

> First, capital outlays must be minimized in any successful testing system, or it must pay out in terms of the total cost of the system which it replaces. In production, the device must be production-line oriented and multifunctional in order to test 100 percent of the highly individualistic product which I have described.
>
> The device cannot be too delicate or too time-consuming per unit inspection, and it must be easily maintained.
>
> Consistency – it must produce identical values for identical items wherever they may be installed.
>
> Translatable – it must predict results to the engineer which will be confirmed in nature and at the same time will have meaning to a layman.
>
> And finally, measurement – it must either give absolute values which relate to real life or measure departures from a prescribed standard which in turn can relate to real life. While we would expect routinely to confirm test results by on-the-road testing and other evaluations to destruction, we must relieve the customer

of the extraordinary expense of the destructive testing inherent in the present draft grade labeling and other Government regulations.

In closing let me once more review the nature of the beast.

- Tire manufacture and sales is a highly competitive industry. Its normal margin of profit after tax is generally less than 5 percent of sales.

- A tire may be designed and constructed of a wide range of materials and engineering concepts and yet perform the same job. Early in my experience in the business I computed that the design engineer for passenger tires had some 3500 decisions to make as to shape, fabric and construction before he settled down to the basic preparation of the specification. Since that time two or three additional fabric materials have come into use, and two new cross sections or profiles have entered the passenger market alone. So, theoretically, our poor designer's options have multiplied by at least six.

- The finished tire is an indivisible unit unlike a car, a radio, or a refrigerator, and with the possible exception of repairable punctures, the tire must run its life without changing any single part. If it is unsatisfactory, it must be replaced totally.

- Once a tire has run its full life, it must be strong enough to be retreaded and do it all over again.

- Each tire is likely to differ slightly from the norm because it is the output of an artisan assembling a large group of components, each one of which is subject to variations from standard. Sampling, therefore, does not give absolute assurance that each tire in the batch behaves like the sample.

- Each tire performance in real life is affected to widely measurable degrees by a variety of factors, not the least of which is the human being.

So the challenge to your technology is this: Are the measurements of a particular parameter significant to the consumer, to the Government and to the industry? If so, are these measurements significant enough to pay out their cost by eliminating some current and more costly practice? If they are, you've got something! And if they're not, you've got a scientific paper which will appear in some journal of limited distribution and which will answer with great precision questions which no one will ever ask.

CHAPTER III – GENERAL SESSION

PROGRAM INTRODUCTION

Paul E. J. Vogel, Program Chairman
Army Materials and Mechanics Research Center
Watertown, Massachusetts

Good morning. As a native Bostonian, I hope you take some time to visit the many interesting sights in Boston. We're proud of our city, and there is much to be seen here. In addition, Boston is located in a lovely historic area. There is one bit of local history which is of particular interest to this group.

It was 135 years ago that Charles Goodyear – no relation to the company with the blimp – in Woburn, Massachusetts, about 20 mi north of here, developed his first work on vulcanization, showing the genius that the Yankees have. Another genius in my now-adopted town of Marshfield, about 40 mi south down the coast, was Daniel Webster. Now both of these men thought they saw a fortune in the rubber industry. Goodyear never did make any money because Daniel Webster defended Goodyear's patents. Webster made a dollar, though, and a few bills that Goodyear ran up in pursuing his efforts, plus Daniel Webster's rather high legal fees for those days, made poor Mr. Goodyear die some $200,000 in debt.

It is a great pleasure to see so many old friends here from so many distant points – from Hill AFB in Utah, Red River Arsenal in New Boston, Texas, and from the Army Maintenance Plant in Ober Ramstadt, Germany, to mention a few of the most distant. During the survey study that was mentioned by Dr. Gorum, most of us met before, and your contributions to the study are now being wrapped up into the final report.

I think that the earlier speakers have done a fine job of covering all the material that I had planned to use in my program introduction, so without delay let us now get on with the program.

NDT AS APPLIED TO VEHICLE SAFETY

Adelbert L. Lavery
Transportation Systems Center (DOT)
Cambridge, Massachusetts

ABSTRACT

Several questions affecting the application of nondestructive testing to transportation systems are discussed. The discussion examines in detail the following questions:

1. *Why is nondestructive testing of interest?*

2. *When should nondestructive testing methods be applied?*

3. *Where in the transportation system can nondestructive testing be applied?*

4. *What are the steps in applying nondestructive testing?*

Emphasis is given to the identification of factors that influence the "Cost of Inspection". Finally, a comprehensive program to evaluate nondestructive tire testing methods, sponsored by the National Highway Traffic Safety Administration and performed by the Transportation Systems Center, is briefly discussed.

This morning I'm filling in for my boss, Dr. John, the head of the Mechanical Engineering Division. The topic that was selected was "NDT as Applied to Vehicle Safety". I'd really much rather talk about NDT as applied specifically to tires, but I think you will be hearing a couple of days of that; so without further ado, let me get into my talk.

I'm sure that each of us here today is very much aware of the general capabilities of thermal, acoustical, and ionizing radiation-based inspection as a diagnostic tool. These particular subjects, of course, are the primary topics for this meeting. In addition to the above three classes of methods, there are many others based on principles such as optics, dye penetrants, and magnetics, to name a few. The potential user of nondestructive inspection methods for vehicles and components can draw upon a vast array of these well-developed technologies, with the supporting industry able to supply both excellent hardware and very competent applications engineering. Later in the meeting, we shall be hearing papers from several of the companies currently serving the rapidly expanding nondestructive inspection tire market. The Department of Transportation, Transportation Systems Center, has been deeply involved in the development and evaluation of nondestructive methods for tire inspection for several years. This work is being sponsored by the National Highway Traffic Safety Administration's Research Institute. We are very encouraged by the increasing level of interest in this applications area, and we feel that a good example of the increased interest is evidenced by the attendance at this meeting.

The general subject of nondestructive testing as applied to vehicle safety is, as I said earlier, a very broad and complex topic. In view of this, I would like to limit this scope to a general discussion and review of several questions that a potential user of NDT should address. The hope is that a somewhat philosophical look at the rationale behind the application of this technology will serve to provide a focus and balance in its application. The questions I would like to look at are: Why is nondestructive testing of interest? When should nondestructive testing methods be applied? Where in the transportation system can nondestructive methods be applied? What are the steps in applying nondestructive testing? These, as many of you recognize, are the classic why, when, where, and what so often used in engineering. The answers to these questions will, of course, vary depending upon the specific application. However, the generalized answers do tend to provide a potential user with a better understanding of the application requirements.

The first question, "Why is nondestructive testing of interest?", can have many answers. The one I prefer is that nondestructive testing is used to verify that a part meets or exceeds a minimum requirement, and the part cannot be damaged by the inspection. The inspection requirement that the part or component must meet may be established by the component manufacturer, the industry using the component, or a regulatory body. The second aspect, that of not damaging the part, is really what nondestructive testing is all about. In the transportation area, the primary

application of nondestructive testing is for manufacturing quality control at the point of manufacture. Inspection is usually performed by either sampling or 100 percent inspection methods. As we heard earlier, the application of nondestructive testing to tires may perhaps best be applied in 100 percent inspection to take care of the random process which occurred during the buildings.

The second question, "When should nondestructive testing methods be applied?", can really be summed up by whenever they are cost effective. While the cost of inspection will follow a set of criteria and can be predicted for most circumstances, the benefit side of the cost effect miscalculations will vary considerably depending on the considerations used. These considerations, of course, will be a function of the organization performing the calculations. For instance, the factors used to calculate benefit for aircraft inspection would be quite different from the benefit calculations of an aircraft wheel manufacturer. The factors influenced in the cost of inspection will be discussed in greater detail a little later.

The third question, "Where in the transportation system can nondestructive testing be applied?", can be answered by looking at each phase of a product's life cycle. The first phase, that of product development, represents an increasing applications area for nondestructive testing. The majority of the applications in this area are related to the evaluation of the product's suitability for use under service conditions. Nondestructive testing can often shorten service testing by the early detection of flaws and the measurement of their propagation. Holography is a method that is finding application in the development of tires, and during the manufacturing phase of nondestructive testing, it has found its greatest major industrial use. It is used in many industries as a routine quality control tool. The applications include both in-process inspections and final inspections. The next phase of a component's life cycle is its in-service use. It is during this phase that component failure must be maintained at a tolerable level. Component failures can usually be attributed to one or more of several factors. These factors include the manufacturing-related ones such as design deficiencies and material deficiencies. The in-use factors will include wearout and abuse. While it is certainly true that manufacturing controls can minimize failures due to related factors, they can never eliminate the in-use failures due to abuse and wearout. Because of this, the application of of inspection by nondestructive methods to the in-service phase will provide both the greatest challenge and the greatest rewards for NDT. Many of the components of a vehicle are suitable for either rebuilding or remanufacturing. In some cases a component will be rebuilt many times thus extending the product's life cycle. Critical vehicle components subject to use-induced failure modes should be inspected to determine their suitability for remanufacturing. Nondestructive testing is the only candidate for this inspection role. Military aircraft tires that may receive many retreading cycles are, in selected cases, being nondestructively inspected to eliminate tires with significant separations and other defects. Using the simplistic approach shown in the first couple of questions, NDT seems to have a potential application in each of the major phases of a product's life cycle.

The fourth question, "What are the steps in applying nondestructive testing?", will require more comment than the previous questions. This is primarily because how well these steps are performed determines the success of any particular NDT application. The first step, identification of inspection needs, provides the framework for the subsequent selection of the best inspection method. It is during this step that the types of defects that must be detected are identified and their characteristics specified. Defect criticality must be determined so information on defect size, orientation, and location can be factored into the inspection method requirement. Information concerning time-to-failure for the failure mode is also required. Special factors such as time of inspection, allowable false alarm rates, defectiveness, environmental conditions, and other factors must be identified and made part of the NDT inspection need. The last factor and one of the most important is the potential inspection benefit. The benefit may be based on purely economic factors. This type of benefit is typical of that used by component manufacturers, and it does provide a reasonable measure upon which to evaluate possible NDT methods. With recent court decisions that a manufacturer and the designers can be held liable for improper product design and quality control, the inspection benefit assumes an expanded role. As an example, inspection records could find possible use in legally demonstrating adequate product control. With the above identification and inspection needs, the next step is to establish objectively the NDT method availability. In this step, the NDT methods having promise for detecting the types of defects should be investigated to determine which ones can reliably detect the defect. Often more than one method, or variations of one method, are found to fulfill the detection requirement. Each of the candidate methods should be analyzed to determine the cost of development necessary to attain the rate of inspection, automation, and selectivity to insure a successful application. These data can be used to determine cost of inspection for the promising candidate methods. The third step, that of selecting the method, is essentially automatic if the first two steps are well performed. The last step is simply to pick the method that meets the technical requirements established by the first step and meets the smallest ratio and cost benefit considerations.

The cost is determined by the fixed and direct cost divided by the unit productivity. It is desirable to determine the cost of inspection for a single unit as it is this cost that is passed to the consumer or customer. The fixed costs for each inspected unit are the equipment installation costs figured at a yearly rate and the annual cost of the space used by the equipment. The direct costs are comprised of the operator's labor, equipment maintenance, and consumables. In addition there are costs associated with training, calibration, and startup that must be considered in a detailed cost estimate. The productivity is the inspection rate times the operating time in the same units times an efficiency factor. This efficiency factor accounts for maintenance time, training, and other considerations that will limit the productivity of the device. It should be noted that, when the equipment has a higher rate of inspection than the application calls for, the lower inspection rate should be used in determining the cost of inspection. The use of these principles in analyzing the situations being considered for NDT applications will give the policy makers, whether they are private or public, adequate and objective information needed for decision-making.

Let us turn from the automotive world and look at another mode of transportation for an example. We have some data on wheels used on railroad freight cars. These wheels are made of either forged or cast steel. In the approximately 300 wheels that fail yearly, it costs about 7 billion dollars in damage to rail equipment and wayside. This does not include damage to lading or other factors such as time delays or potential business loss due to customer dissatisfaction. If it is assumed that the identification of defects, failure mode, and defect criticality analysis were to show that it takes 1,000 miles for a detectable defect to fail a wheel, then an inspection of each wheel at least every 1,000 miles will be required, and in this case the numbers are small – we have about 14,000 wheels in service. We assume that the target benefit is to reduce the loss by 3 million dollars. A method that is about 50 percent effective could be selected. The maximum cost of inspection, of course, is the number of inspections per wheel times the number of wheels in use divided into the cost benefit. For this example the cost of inspection could not exceed 1.3 mils. The total funds for implementing such an inspection system are obviously approximately 3 million dollars annually. This example is indicative of the difficulty of in-service inspection throughout the transportation field. It must be mentioned that a somewhat similar system for hot-box inspection is in use on many of the nation's railroads. These systems are based upon real need; they have been shown to be cost effective and they are privately funded, thus one can conclude that the job is not really impossible.

In closing, some of the considerations relating to the what, why, when, and where of nondestructive testing have been briefly reviewed. It is clear that safety is in part related to the condition of the components that comprise the transportation system. It is in the determination of the condition of the components that nondestructive testing offers a major promise. The promise will not be fully realized if the approach is one of selling a favorite idea. The time has come to analyze objectively and to use the most cost effective method to achieve vehicle safety through NDT.

Before leaving, we have a facility in Cambridge where we have been doing tire inspection for several years. It has been set up on the Agenda for Wednesday afternoon and Thursday afternoon for people to visit the facility and see the various types of equipment in operation. On both afternoons we hope to arrange for a bus to leave at 2:00 p.m. from the School Street entrance.

THE RETREADED TIRE

Paul Atkinson
Tire Retreading Institute
Washington, D.C.

ABSTRACT

This presentation will follow the general guidelines given below:

1. *The history of retreading, with a look at things the way they were and the way they are.*

2. *Economic importance, this speaks for itself from the processor to the user.*

3. *The present method of testing, the way it's done and the limitations of the methods.*

4. *Developing a retreading process, controlling and proving that process, testing the process, and finally, the process as a test.*

Shortly after the turn of the century, many tire men began worrying about the fact that tires were wearing out; and after they wore out, the principal portion of the tire still remained, only the tread area had worn away. Back then that didn't take very long to do, either. American ingenuity then came to work, and they started worrying about restoring the tread back to the tire and reusing the body, as cobblers had done with shoes. In the earliest days of retreading, they took tires that had failed for some reason or other but still had a good tread design left and applied this to another tire that had worn out. Actually, the first attempts at this were in riveting the tread onto the tire. Enough of it was done so that they actually began to manufacture these treads and put them on tires, and they even got some saddle makers who sewed them onto the tires. As long as cars were operating at the violent speed of 12 to 15 mph around town, they got by. They then tried to cure rubber right onto the tire; they had a matrix made and it went over one-fourth of the tire; they cleaned up this area of the tire and cut the surface off with knives so that they got the dirty surface away, applied rubber to this, and put it in the mold. Sand bags, spring coils, and mandrels of various types were used to apply pressure inside. This was heated and cured on the tire, and the tire would be returned and the process repeated again. This was done four times, and the tread was then on the tire. Of course, American industry has always been trying to speed up production and lower operating costs, so later on a one-third circle mold was used. This cut the production needs greatly because the tire was cured only three times. Finally, the Supermold Corp. came up with what was called a full-circle mold. In other words, it would accommodate the entire tire at the same time. As crude as this was, this was really the forerunner of the highly automated equipment that we're using in tire retreading today.

During World War II our sources of raw material were cut off and all of our tire needs were for military uses. A crash program was performed that resulted in the discovery of synthetic rubber so that we could keep rolling. Those of us who stayed around and ran the tire business during those days did everything in the world to keep vehicles rolling. One of the processes that we used was to take a tire that had worn out and buff the surface of it away; we then took another tire where the rubber had come loose from the cord – there had been a separation usually in the bead area of the tire because they were made of cotton cord and had a rather high incidence of bead failure – and cut the sidewall of the tire away. Then the tread area was turned wrong side out and put over another tire to hold it – this would put the cord portion of the tire out. Then we buffed the back side of this away so all the cord was buffed away down to the rubber, and the worn-out tire that had been buffed was cemented on. Gum was put over the tire, and then a lot of solvent to make it slick, and the tread was put down upon the tire. The tire was then put into the mold that the design had been ground off, and we actually cured the gum on the base of it. (This today is known as a precured tread in the industry.) Adolf Hitler was having the same problem – that of keeping enough tires around to keep the vehicles rolling to fight a war. His engineers came up with the idea of curing a tread separate from a tire, then of buffing a tire off and applying gum on the tire and putting this tread that had already been cured onto the tire. They wrapped steel bands around this tire to hold it on to apply some force; these were sent down to General Rommel, and he buried them in the sands of the Sahara Desert for

two weeks. The heat of the sand cured the tire or cured the gum at the base of the rubber. This was the formation of a process we know today as the Bandag process and is a widely used system of retreading in this country.

In those days we had to try to get another mile out of every tire, and we took many tires that were not repairable and repaired them; we took many tires that were not retreadable and retreaded them. We could very happily have run our industry with today's scrap piles. But many processes were developed out of this, and this is the old necessity being mother of invention, and with this we've come up with many processes through the years.

Operators of vehicular fleets know that one of their highest costs of operation is tire costs. Now these costs can be controlled, and a good fleet operator is a valuable, valuable man. He can save many times his salary. The tires are controlled by purchasing the right tire in the first place – the tire that is properly applied to the job – and properly maintaining it on the vehicle, giving it correct mounting and maintenance procedures, correct inflation, and then primarily getting it pulled off the vehicle at the correct time so that it can be retreaded. The tread rubber portion is about one-third the cost of the tire, and it can be restored to the tire for about one-third of the original cost of the tire. As that tire can be retreaded repeatedly, every time it is retreaded it lowers the total cost of operation because the cost of the operation must be figured from the time the tire is originally purchased until the time it goes into a scrap heap, so it is a principal means of holding down this cost.

Another highly important facet in the retreading picture is the fact that this year there will be produced approximately 12 billion pounds of rubber waste, and the greatest portion of this is in worn-out tires; that creates a tremendous problem throughout the country because you can't compact rubber, it won't decompose, and it becomes a great problem to dispose of these junk tires. In New York City they are paying 25 cents a tire just to get a passenger tire hauled off; even out in the plains of Kansas they are paying 15 cents a tire. So this is a serious problem, and the recycling of these tires into retreading helps tremendously in removing them from the scrap heap.

In 1955, the National Tire Dealers and Retreaders Association formed a new division called the Tire Retreading Institute, and this was to be a staff of people who would not represent any equipment company or any materiel company. They wouldn't have anything to sell or anything to protect. They would set up procedures for retreading and help retreaders make a better product. Now this was the birth of the Tire Retreading Institute, and over the years TRI has built a staff of eight field men, of which I happen to be one.

Our field men (not speaking of me) are the finest men in retreading to be found anywhere in the United States and the world. Backing these men is an advisory staff of tire businessmen geographically located around the United States; men who are successful in their business, highly respected people to back this field staff up and direct them in their actions. We also have a research facility at Heflin, Alabama, where continual research is being done on new approaches to retreading. Currently we are doing in-depth research on radial tires. We've fairly well phased out our work with the fiberglass tires, but anytime any new procedure comes about, we try to go in-depth with the correct procedures for handling this type of tire and retreading. We also have a school at this facility, and we give courses in basic retreading to men who are entering the field and want to know the correct procedures for doing these various jobs; then we have an owner-manager-foreman school; we have schools for representatives of equipment and supply companies so that these men can know something of the true action of what is taking place in the retreading of tires. We have a lot of people who own a place and are ashamed to go into the shop because they don't want to have to tell the people they don't know what to do. They come to the school to learn something about what's supposed to be going on back in their own shop. But our foreman school is designed to give in-depth training on problem solving and quality control and the parameters that a quality shop has to employ. We have people from all over the United States at this school. We also have regular meetings among the field consultants to bring in problems from the field and also to try to keep them abreast of everything that is taking place anywhere in the world in retreading.

Our membership is around 800 members, and we include the largest and best retreaders in the United States. We also include the smallest and the best retreaders in the United States. In order to remain a member, the member's shop is annually inspected by one of the field men, and they go in and do a real in-depth inspection of his facilities, of his equipment, of his personnel, and of his adherence to the TRI procedures. His adjustments are analyzed to try to find where he's deviating and how this can be brought back in and these adjustments eliminated. About 15 million retreads were made by TRI members last year, and throughout this membership there are dramatic stories of adjustments reduction after changing to proper procedures and the TRI process. Some members get more precisely into the process than others, and consequently they invariably have much lower adjustment problems. Our process and our shop operating manual go to all of the equipment suppliers, all of the rubber suppliers, the other associations, trade associations, and retreaders all around the world. As new procedures come about these people are

all advising us as to what their new procedures are, and we, in turn, try to find where these fit into our processes and, if they don't, what needs to be done to bring them in.

About two years ago we ran 33 tires from 11 different dealers scattered geographically around the country. These tires were all carefully prepared and hand-followed through to see that they followed the process to the letter, and they were all sent to an independent testing laboratory where a full 109 test was done on the tires. All 33 of the tires passed without a single failure. We're continuing to test procedures, and we do make tires that fail, and we do many things that we shouldn't. Currently in the retreading of radial tires we're trying to find out many things. People say "don't do this", and we do that to try to find out why you "don't do this". We try to come up with what exactly it is that will make a tire run successfully. But we have spoken of tests — wheel tests, plunger tests, road tests, and pull tests — these are all destructive tests, and the thing we're trying to do here today is talk about nondestructive testing.

A tire that is prepared by a proven process will be successful. By testing the manufacturing agency's procedures you are testing their products. The agency making the process must continue, usually by destructive testing, to prove the process and test in-depth for any changes to this process. TRI is not the only quality control process in making tires — others work toward a process also. Probably one of the most notable is the Bandag Corp. who have had patents that have protected a particular type of retreading, and they have done this deeply in research on their own system. Today there are many other companies that are in the pre-cured business, but Bandag has specialized their research down to this one particular vein. They publish a process guide for their franchisees. It so happens that the Bandag Corp. is a member of TRI, and annually we go in and inspect their facility in Muscatine, Iowa. They are inspected just like the rest of our members, and we go in and make recommendations to them to enhance their process. They, in turn, are always feeding information and suggestions back to us. A high percentage of the Bandag shops are also members of TRI. Bandag makes regular inspections into these various companies' procedures. Then TRI does the same thing. You see, we are not competing processes, we actually complement. There are a number of processes, and all of us that are in this business feed our information to one another so that we know what the other is doing and try to help and complement each other, not compete with each other.

Whatever the process is, the originator of it has to test it continually by every known method, and he has to inspect the facilities of people who are using it to see that these people are following the process. At this point the process becomes a true test of a good tire that will successfully run. This is really true nondestructive testing, and it's the feeling of the Association that it really is the very best form of mass testing because no test is anything more than the test of that one tire. As somebody said earlier, each tire is an individual, and it certainly is. When we run a plunger test on it, we know about the plunger of that one tire, but we don't know about the next tire. When we test a process, though, and we adhere to this process, then that process becomes a test of every tire that is made in the facility, and the National Tire Dealers and Retreaders Association and the Tire Retreading Institute share in the view that the very best testing of all is nondestructive testing and it's closely following a proven process.

THE AIR FORCE PROGRAM FOR NDI OF AIRCRAFT TIRES

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ABSTRACT

The Air Force's interest in NDT of aircraft tires was generated by tire failures in service and on dynamic test equipment. Interest in this area lies both with new and rebuilt tires. Objectives are to evaluate various NDT methods available, projecting their possible use in laboratory and in support of field service problems, and to consider for possible manufacturing quality process control necessary to correlate size and location separations with actual performance. Present failures indicate that tire size does make a difference in NDI defect identification.

I think our interest in Air Force tire inspection is very similar to yours. We are interested in quality and reliability, except, I think, we look at a little different aspect of it. When we have a failure, we have a bit more involved than just a flat tire and the need to get out, jack up the vehicle, and fix the tire. We could lose our aircraft upon takeoff or landing, so we are really critical of our tires.

I think sometimes we have to look pretty deep to get the quality control we really need. We have a lot at stake in the aircraft industry as we look at the quality of our tires. I find that the major defect we are looking for is separation in the sidewall and the tread – basically it's a separation type thing.

In the Air Force we find that the tires we're concerned with separate for various reasons. Some of them separate from a service impact which occurs during use – a tire hits a rock, a cement abutment, or something else. We find that this could give us a separation. We find that broken cords will give us a separation or initiate a separation either in the original manufacture of the tire, in the recapping of that tire, or during its service life. Another type of separation is from a weak bonded area which is put into a tire either during the initial manufacture, or by use, or by a recapper. We also find that there are some inclusions or foreign objects that could accidentally get into a tire, possibly during recapping, and that there may be voids and pockets in the tire. Now this is a little different than what has been spoken of previously, I understand, but we have found that a lot of new tires and recapped tires have these built-in voids, and this is what we are looking for. In looking for these particular things, we're trying to evaluate the NDI methods that will find them for us. Some of the parameters we are using to evaluate these NDI methods, the parameters that we are particularly looking for, are: first, the defect's size and location, and I say this could even include the depth of the defect; second, what tread area we are talking about – is it up near the top or near the bottom? We find we have separation problems all the way through the tire. We want equipment that will give us good resolution as to what the defect is. For example, in one of the methods we are using currently, we are having trouble with the balance pad inside our tires; it's given us a particularly peculiar reading which we can't correlate. We're finding that some vulcanized areas are giving us bad readings. We have to have an NDI method that will give us good resolution. We would like equipment that has been built for some time, that has been worked for some time, that is easy to operate, that has proven to be reliable. Also, I think a really important consideration is the cost of testing. I don't just mean equipment, and the expendables that go along with the equipment, but also the testing time. I think this is an important built-in cost in the inspection.

As I see it, our particular interest in NDI, that is, where we're going to use this type of equipment, is in three areas: First, we will use it on qualification testing with our dynamometer; that is, when we run tires to evaluate them, we want to test them NDI-wise to see where the separations occur and grow. Secondly, we want to use it on some field service problems; for example, if we have a tire or several tires out of a batch that fail, we want to inspect the rest of that batch in our fleet. Thirdly, we want to develop some sort of quality control standards to put in our procurement documents so that we can be assured of a consistent quality level. I don't want the original manufacturers and recappers to get me wrong; I don't want to upgrade the quality level that we are at; all I want to do is make it a consistent quality level so we don't have a lot of premature failure

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The current methods which we have been investigating quite thoroughly are X-ray, ultrasonics, and holography. We have thoroughly studied them, and I am sure we will hear later on today some of the evaluations of these methods and what they can do and what they can't do.

The procedure we are using to evaluate the tires is to induce defects in recapped tires. The method used is to cut certain sizes of polyethylene, various squares, circumferences or what have you; we put these on the buff line, after the tire has been buffed, and recap on top of them; then we try to find the defects. Now, I know and you know this isn't a real defect and what we're really trying to find. There's a lot to be desired in this kind of evaluation, but it speeds up the program of trying to induce defects in the tires and trying to evaluate equipment. We run into a lot of problems with it; we don't really know that the separation is the size of the defect we put in there, but it gives us an evaluation so that we can compare one method with another, and this is what we are currently trying to do. We are trying to get each NDI method up to its full potential and then inspect comparable tires. We know that if we use natural defects that occur, it is going to be a lengthy process. We know we are going to have to get into it eventually. With the method we are using, we have found defects down to probably 1/4 in. in diameter. We feel this a great improvement over the old method of hitting that recapped tire with a tire iron. We feel we have come a long way; I think with more evaluation we could probably not do better than that, and I don't think we have to do better than that. But I think with more evaluation we will be able to segregate those indications which are false.

From our experience we have found the size and speed of the tire is particularly critical as to whether the separation will grow or whether it will stay static. We find that the smaller tires, the fighter tires that travel at a greater radial velocity, not the velocity of the aircraft, have more of a tendency to have these separations grow, separate and enlarge; whereas in our bigger tires, such as those on the B-52's and C-135's, we find that the defects or separations sometimes will stay static over a long period of time. Consequently, we have a varied problem even in our own fleet.

I think one interesting factor we have come up with, which might cause a little question or a little comment, is that on some of our larger tires which we're currently recapping we have found that the first and second recap is becoming as reliable as a brand new tire. Now I could get some comments on this and I probably will, but our conclusion is that we have eliminated from the system many of the initial defects in the new tires.

Our future testing program is: first, to continue evaluation on the defects which we have built into the tires until we are satisfied with what we can get out of each NDI method; secondly, to study separation growth in tires by running them on a dynamometer and then through an NDI inspection which we consider to be good; thirdly, to use these results in some manner in improving the reliability level by establishing an NDI requirement in the procurement of new and rebuilt tires.

QUESTIONS AND ANSWERS

Comment by Mr. Thomson: Before you even ask the first question, let me state this. The man who was to give this talk is a tire engineer. These are his notes; I gave it for him. I'm an NDI specialist; I've worked in NDI of metals for many years, so I'm not going to be able to answer all your questions.

Q: Mention again the three methods that you are exploring at the moment – NDI methods.

A: X-ray, ultrasonic and holography. We are not particularly working on infrared at the current time because we have no way of spinning the tires, and we haven't had a source.

Q: What method do you use to find a fault 1/4 in. in diameter?

A: I think it's been proven so far that we can find that size of a defect with infrared, with holography, and with ultrasonics.

Q: All three?

A: All three. To my knowledge we have found them with all three.

Q: You mentioned several times that you have found a lot of failures. Do you have any idea what the cost of the failures actually are?

A: You mean an average cost of a tire failure on an aircraft?

Q: Or the total cost to the military per year.

A: I have no figures in this direction. I have seen some very costly failures, and I have seen some that are not so costly. Most of them are dynamic failures; they're not static; they don't sit there and go flat. I have seen them go flat on taxiing; they just go flat, and you change it and it's just fine. I have seen them go flat on takeoff where the tread flies up underneath and bursts hydraulic lines; they lose their brakes and we lose an aircraft. I have no average cost. I don't know if these figures have ever been obtained. But we can lose an aircraft upon losing a cap.

Q: Is a 1/4 in. separation detectable by X-ray?

A: No, I didn't say X-ray.

Q: Do you have a figure on whether most tires fail on takeoffs or on landings?

A: He *[meaning Mr. Eure]* says takeoff. If I was to pull it off the top of my head I'd say landing. Take your choice.

Mr. Vogel: Gordy, do you want to take the mike for a minute for a comment on that?

Mr. Eure: Yes.

Mr. Vogel: This is Gordy Eure from Thompson Aircraft Tire Corp., Atlanta, Georgia.
Mr. Eure: Most of your aircraft tire failures will occur on takeoff. An aircraft tire is made to carry weight; it's not made to roll on the ground. Consequently, on a takeoff you've got a lot of roll and then you get high speed, so this is where your failure occurs. On landing it comes in cold. Are there any other questions?
Mr. Thomson: It's the heat involved in weight and high speeds – he's right, I'm wrong. I'm not a tire engineer.
Q: On the aircraft tires that you have examined, how many of them can you correlate to separation failures?
A: We correlate about 99 percent or better. In other words, we correlate it back to separation, then the separation is caused by something else.
Q: Do you have a recap shop at your base so that you can set them up?
A: No, all our recapping is done by a contractor – various contractors.
Q: What is the average life of an aircraft tire from brand new to recap?
A: This varies with the size of tire and with the weight in the aircraft. It's impossible to answer it correctly. Let me say this, I'll cite one example I think is correct. Again, I'm not a tire man; I'm an NDI man. I recall off the top of my head that there are about 60 to 70 landings on an F-4 before the tire is worn out. Here, I'll get corrected.
Mr. Eure: No, on an F-4 you are probably right, it's probably even a little bit less than that – about 35. It was 6 when the F-4 first came out. When the C5A first came out, with every landing they changed one tire. Now the C5A is up to approximately 150, give and take weather conditions, depending on heat or winter time or something like this, and load. The normal jet tire that you think of commercially is anywhere from 150 to 200 landings per tread. The retread will give you approximately 15 percent more landings than the new tire. To correlate that in number of days, on a commercial airline, you're looking to between 16 and 30 days to pulling a tire.
Q: The question concerning your high correlation of failures and detected separations: Is this high correlation between the failure and the original separation or between all detected separations and failures? I'm concerned with their statement that 90 percent of the tires have correlations. Does that mean that 99 percent of these tires have anomalies originally? Does that mean that 99 percent of these 90 percent are going to fail?
Mr. Eure: Well, as a retreader for the Air Force, Navy and commercially, we'll dispute the 99 percent because we'll lay the majority of all failures on operational failures and not on the tire itself. If you get a tire out in the field, as most of you people know (you're mostly tire people) inflation has to be one of our biggest killers. In your passenger tire you're talking about 20 or 30 lbs of air. In aircraft tires we're talking about 200, maybe 300 lbs in some of these fighters, and it's easy to get a 15 percent drop in air pressure. Now that really kills us when you're talking about maybe 20 actual plies or maybe 24 actual plies. You get that kind of deflation in the tire, you get that much more flex, you get that much more heat, and you're just really asking for trouble. Clarence did say that he puts the 99 percent on tires he has examined, so I can't really dispute that, but I can dispute 99 percent of all tire failures.
Q: Could you clarify that correlation a little better? If all tires have a few separations, then backwards correlation would always be 100 percent. But does that mean that the separations always cause failures? Can you tell us what is really observed?
Mr. Eure: Can you say that all tires have failures? I personally can't believe that – maybe they do, very small, very minute. Right now the category that we're going under for the military is finding 1/2-in. separations, 1/2-in. failures, 1/2-in. anomalies. We're not even sure that a 1/2-in. anomaly will destruct a tire. The tire might be perfectly good with a 1/2-in., we don't know. There is no data that says a separation will cause a failure; it's just not there. Now if you can get a separation 3 in. long or something like that, it will cause a failure, but we run quite a lot of tires on the dynamometer, unfortunately, and that dynamometer will just tear up tires anyway. You can have a perfectly good tire and there's not a thing in the world you can do about it. Remember the aircraft tire may be carrying somewhere in the neighborhood . . . well, a main tire, let's say, for an aircraft is going to carry approximately 20 tons. In other words, it is carrying a heck of a load; you take that 20 tons per tire and slam it against a wheel doing 200 or 225 mph, and you get damage there, so you can't really say that a separation is what caused your failure. And I probably strayed away from your question because I can't answer it, and I don't think anybody can because there is just not that kind of data available.

IS THERE A SUBSTITUTE FOR THE ROAD TEST? A PROBLEM

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ABSTRACT

The cost and time to conduct actual on-vehicle road tests to qualify and control the quality of tires is becoming prohibitive, especially in light of rising costs and increasing funding restraints.

With the emphasis on safety the Army cannot afford not to test. However, because of limited funds, the Army cannot afford the tests. The answer to this paradox is a rapid, low-cost simulated road test. Ideally, this method should be nondestructive, require only several seconds to inspect, and make a reliable prognosis of the remaining useful life.

This question addresses a military problem, the solution of which will have application in the commercial field.

The paper will cover a review of military requirements, field usage, current programs, and a request for a committee study.

The title of my problem refers to the road testing of tires, specifically road testing of military tires. There are two ways of testing tires:

1. Road testing
2. Laboratory testing

The attempts made to evaluate tire reliability in the laboratory have not been too successful. The problem is that all of the factors which influence tire performance have not been simulated in laboratory testing; therefore, we are currently dependent upon road testing which is costly and time consuming. Is there a substitute for the road test or can we find a laboratory test that will duplicate field conditions? With this in mind I would like to review briefly the principles of tire testing and the problems of correlating road and laboratory testing of tires.

Tire tests are conducted for two reasons:

1. To determine tire characteristics which influence the operational quality of the vehicle. There are such things as tire slip angle, rolling friction, noise isolation, and tire spring rate. These are generally ride and handling characteristics related to vehicle performance.

2. Tires are tested to determine their reliability during operation. In this case we are talking about wear resistance, fatigue strength, and resistance to concentrated loads. Here we are concerned with the tire as a system in itself.

My problem is concerned with the second case – reliability. How long will a tire perform its function under a given set of conditions? Or simply, do we have a quality product? Let's look first at road testing.

The objective of an endurance road test is to determine tire reliability in service through simulation of field conditions. It also permits us to check the uniformity of the quality of tires produced. Road tests are designed to duplicate field wear under controlled and accelerated conditions. Table 1 shows some of the characteristics or attributes of a tire that are normally evaluated during road testing. Tests can, of course, be designed to test one characteristic more severely than another, and there are, of course, other characteristics which may be of interest in special cases.

TABLE 1
TIRE CHARACTERISTICS

- Tread Wear
- Cord Construction
- Bead Strength
- Materials
- Impact Strength
- Adhesion
- Fatigue Strength

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Let's now look at the factors that influence the results in road testing. Road surface is the road composition, and tire wear is different according to whether the road produces a cutting abrasion or a frictional abrasion action. Road geometry relates to road crown, curves, and road banking. Climate has an effect on tread wear which is most influenced by temperature. Generally, as temperature increases, tread life decreases. Topography is the effect of hills, valleys and the general terrain. The effect of tire loading, of course, is quite pronounced. As the load is increased the wear rate also increases. Probably the most difficult variable to assess is the contribution of the driver to wear since each driver adds his own particular group of variables. Every tire experiences all of these variables which influence tire wear, but in any given driving situation different factors may assume a more dominant role. A tire test should be designed so that all factors influencing wear come into play. The fact that all of these factors do not affect wear equally in any test, or from test to test, probably accounts for the difference in highway tests reported between different parts of the country and between slow wear and fast wear tests. As an example, where three or four tires are compared, the tire with the highest wear in one area, say Ohio, may sometimes have the lowest wear in another area, say Texas.

There have been attempts made to simulate field wear in the laboratory by use of endurance wheels. The most common and the type used at the Tank-Automotive Command is the so-called NBS wheel. The tires are forced against the larger revolving steel wheel, and wear is introduced through rolling friction. In most cases no attempt is made to alter the plane smooth steel surface; however, lugs or abrasive material can be added to the wheel surface. The room temperature is usually held at 100°F, and the load and speed can be varied.

As pointed out earlier all of the factors which influence wear must be present in a reliability evaluation. Factors such as road surface, topography, and some of the driver variables are missing; therefore, this type of wheel cannot duplicate field conditions. Such characteristics as heat resistance, construction, and adhesive strength can be measured on a comparison basis. Other wheels and machines have been built which include an abrasive wheel surface and allow the tire to be pivoted to introduce slip angle as when the vehicle is being turned. The results show an improvement in data, but still they lack all of the factors influencing wear.

Mr. S. C. Ambelang of the Goodyear Tire and Rubber Company recently presented a study of four tire test laboratory machines. The machines varied from a 28-ft diameter wheel to a 14-in. diameter wheel. All had abrasion surfaces, and all but one could introduce slip angles. Mr. Ambelang concluded that the machines did not represent actual service conditions and are oriented toward materials evaluation rather than product performance.

SUMMARY

Laboratory machines are available which provide for load, steer, and abrasive conditions, but they do not provide for the wide range of environmental conditions encountered by our vehicles in the field. Therefore, to assure that our troops are getting a quality product, we must continue to road-test tires, but with rising costs and reduced funding it is becoming increasingly difficult. That brings us back to our original question: Is there a substitute for the road test?

The answer to this question is a method which would quickly and cheaply simulate field conditions. Ideally, the method should be nondestructive, require only several seconds to inspect, and make a reliable prognosis as to the remaining useful life. The final system will probably not result in a single-figure overall rating system but more likely a set of numbers which would qualitatively define a tire.

I have presented a brief overview of a problem which has challenged the Army and industry for many years and, hopefully, will receive some answers or suggestions which will provide us with guidance for further exploration.

THE CALSPAN TIRE TESTING MACHINE

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In 1967, Cornell Aeronautical Laboratory, which had been engaged in testing aircraft and automobile tires for some time, set out to define an advanced testing facility to measure forces and moments on tires for automobiles and also for trucks. They designed into the facility as much versatility and as many advanced features as they thought that they could successfully build into it. Almost two years ago we started construction of this facility, and I would like to describe it to you and point out some of the features which we have in the facility now and some of the additional facilities which we are still in the process of adding. I would like to describe it by showing a movie, but first I will show just a slide (Figure 1). The main feature we were looking for, and most important, was a flat roadway, and we have solved this problem by means of a stainless steel belt 1/16 in. thick – a continuous belt which is revolved over two 67-1/4-in. drums. The surface of the belt is coated to simulate an actual roadway. The object is to have a flat belt, and to resist the vertical load of the tire, we have backed up the belt with a battery of air bearings. This feature has been successful on the machine. The machine has been running for a little over one month. There are also some design features which are interesting, but that I won't describe, which maintain the belt tracking on the drums under the sidewall loading imposed by a steel tire.

The machine consists of a head (Figures 2 and 3) which gives us the ability to steer the tire to a ±30-deg angle, to camber the tire to a ±30-deg angle, and to load the tire on the roadway with up to 13,500 lbs. The machine is built for passenger car tires and truck tires. The maximum size tire we can put on the machine is 46 in. in diameter. The roadway is driven by a hydraulic motor up to 200 mph. The wheel is separately driven up to 200 mph by a similar hydraulic motor. We have enough horsepower in these motors to simulate the inertia of a large automobile. Surrounding the shaft which drives the tire, we have a six-component balance system which we use to measure the forces and moments between the tire and the roadway. The The other features which may make it interesting to the subject that is being discussed today are: we have four belts, and are able to put different types of road surfaces on the belts; we have the ability to heat the air that supplies the air bearing to a very high temperature and, therefore, to heat the roadway; and we have built the controls of the machine around the dedicated computer (Figure 4) which allows us to program in all the various motions and forces on the tire. (I would like to show the movie now.)

With the separately driven roadway and wheel we are able to test tractive and braking forces all the way from full-locked wheel up to the spinning wheel. We also are about to put into operation a water nozzle which will lay a film of water up to 4/10 in. thick on the roadway at the roadway speed to study hydroplaning. We can measure the pressure inside the driven tire, and we also have a connection where we will be able to vary the pressure while the tire is running. By controlling the machine with a computer, we are able to optimize the rate at which we make routine runs. This first operation is the tire's camber so that the balance system can weigh the metric weight of the system to correct the data for the gravitational component. This is the G78-15 tire loaded to the purpose of making the movie. This is our camber ability; you can see that the belt remains on track when we steer the tire. We are going through a normal load sweep on this tire – the wheel is driven by 3,500 psi hydraulic pressure which is too high for a hose so you see we have pipe and flexible joints which make a complicated looking system. Here is the connection where we are varying the pressure in the tire during a run. Now with this machine we are able to generate a carpet plot that runs through a normal force variation at various slip angles on a tire in approximately 15 min. The data reduction is also accomplished in the dedicated computer and is available within 1 min after the run, so that we have a machine that is of use to the research engineer in having the data immediately available. It's also available in production, and in this same computer we are able to fit curves to the data. That's a 160 percent of design loading on that tire – 2,400 lbs. When we are taking data, we are pausing at each load for 2 sec while the computer records the data. Now we have another mode of operation where we can continuously sweep, and we can take data at the rate of about one data point per millisecond. So at 50 mph we are able to get many pieces of data in one revolution of the tire. The computer controls the machine from startup

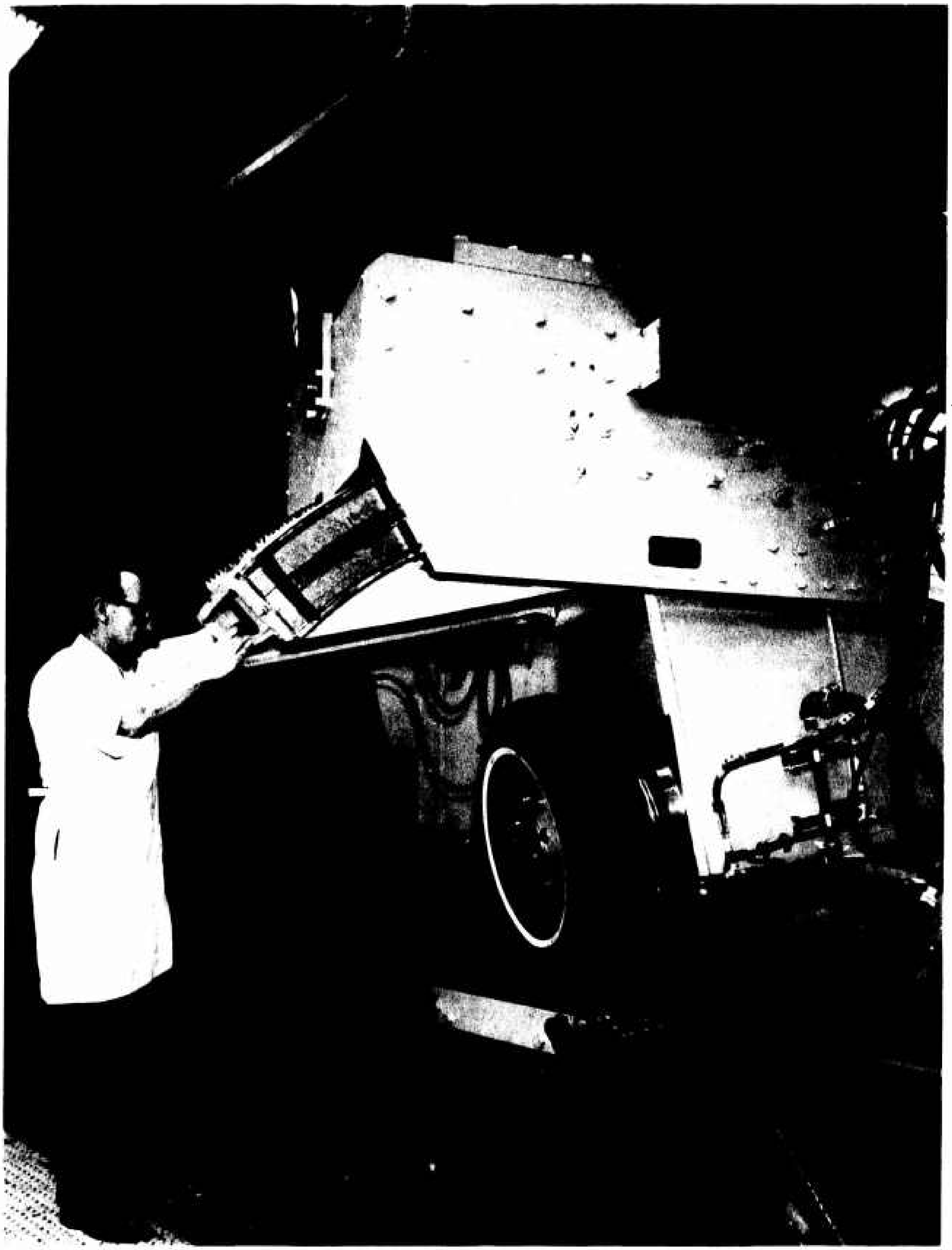

FIGURE 1

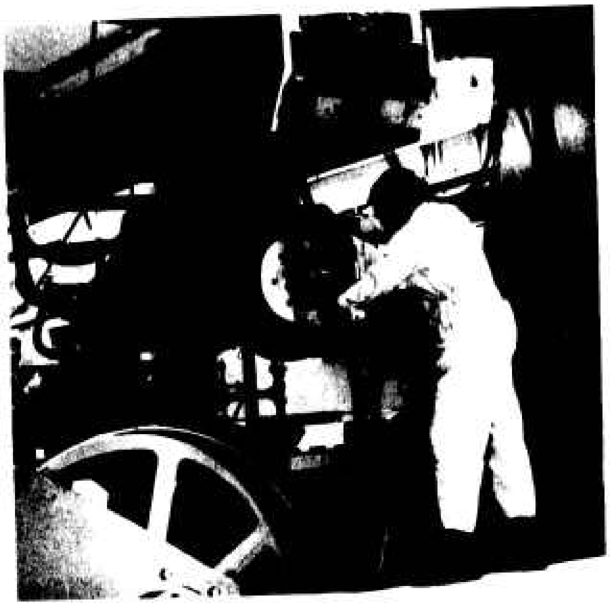

FIGURE 2

FIGURE 3

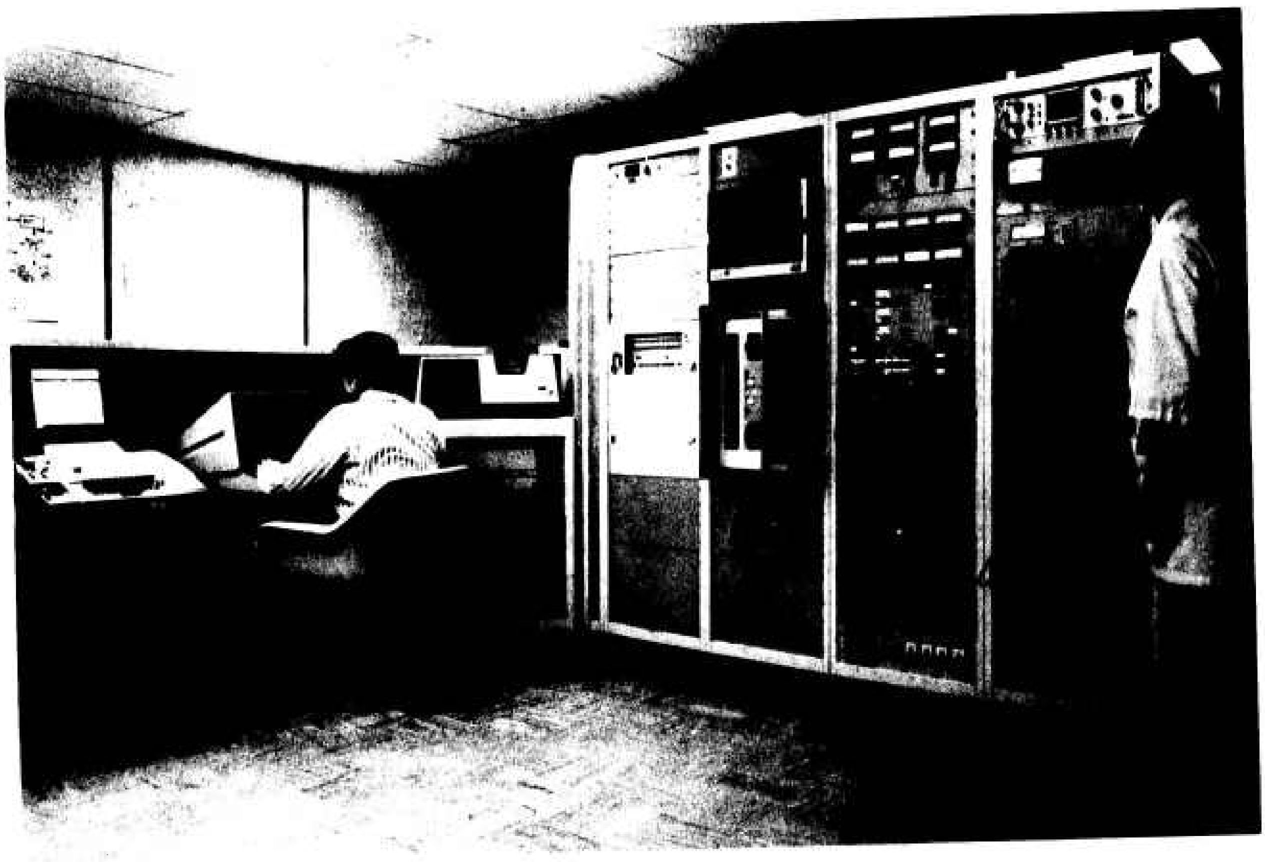

FIGURE 4

to shutdown, and it also monitors all of the indications of failure on the machine. It will monitor the various safety indications, and the computer of course will shut the machine down in the most satisfactory fashion should there be a bearing over-temperature, etc.

Now in the month that we have run the machine we really have not taken enough data and looked at the data carefully enough so that I can show you any results of the effect of wear on the performance of the tire, but we are taking that type of data, and we do expect the machine to be useful in that respect. We have duplicated the program of testing the tire at steer angles used on a trailer on a road test, and we claim good correlation with the performance that we measure compared to a road test on an asphalt surface. One minute after a test we are able to print out lateral force, tractive force, overturning moment, aligning force as a function of various slip angles used at several normal loads, and at the operator's option we are able to plot any of the measured parameters against any of the independent parameters. This is a carpet plot of lateral force versus various slip angles at various normal loads – this being 2,400 lbs and this being, I think, 400 lbs. And we are able to fit first, second, and third curves in the machine to the points. This is 400 lbs, 800 lbs, 1200 lbs, and there is a third order curve, and we are fitting apparently a second order curve to the lines of the constant slip angle – this being 1 deg, 2 deg, 4 deg, 6 deg – and finally we can make a hardcopy to make a permanent record; or this can be stored in the computer, and we can get a second run which can be plotted over the current run we are looking at. So we make a copy of it, and we are ready to go on and make a carpet plot.

We are very pleased with the results obtained in the one month we have been running the machine, and we feel that the accuracy of the instrumentation we have, which is the force measuring instrumentation, will allow us to separate the other variables we have control of such as road speed, road temperature, tire pressure, etc. Thank you.

QUESTIONS AND ANSWERS

Q: Is it possible to measure reliably the slip angle?
Mr. Martin: The slip, camber and normal force and normal position are servo controlled, a servo system, and we have a potentiometer on the mechanism that stirs the dart.
Q: Is the slip angle a function of the deformation of the tire or the deformation of the potentiometer?
Mr. Martin: We are measuring the angle between the tire plane and the roadway.
Q: And how do you do that exactly?
Mr. Martin: It is a mechanical measurement of the angle that we steer the housing which holds the shaft driving the tire. The angle we steered it to the reference plane of the machine.
Q: But this is not exactly identical to the slip angle. The real slip angle is a variation from that. And exactly how do you do the tracking of the road?
Mr. Martin: The road is constrained to a certain direction on the machine – the plane of the tire constrained to a certain angle on the machine. And we define the angle between the plane of the tire and direction of the road parallel as the slip angle.
Q: But you also add some friction?
Mr. Martin: The tire is deformed by the friction between the road and the tire, yes.
Q: How do you provide the necessary stability on the belts to keep them tracking on the drums when you add some slip angle out at zero? What stops the belt from sliding off?
Mr. Martin: That was a most interesting engineering problem. Most belt tracking on pulleys is obtained by steering the pulley onto which the belt is traveling with an active servo system. We allow the pulley onto which the belt is traveling to be mounted on a cradle which is mounted on the forefront underneath the machine, and it allows that cradle to rock slightly; if you push sideways on the belt, you not only tend to push the belt off the pulley, but you also would tend to rock that cradle. The characteristic of a pulley going onto a drum is that it wants to run uphill, so that these two things counteract each other, and the cradle is restrained by a spring, the spring constant of which is matched to allow the amount of rocking. Note it rocks one or two minutes apart. The forces and moments in the belt generated by that slight amount of rocking are very strong and it doesn't take much lateral rocking of the belt. Of course, also, the belts are slightly crowned for stability.
Q: What is the cost of this machine?
Mr. Martin: We were at Cornell Aeronautical Laboratory, a nonprofit corporation, at the time we started this project, and we were fortunate to receive equal grants from the MDMA and the RMA totalling $655,000. In addition, NHTSA gave us a contract to develop some of the instrumentation and to calibrate the balance, and quite frankly Calspan has put in some of its own money. The cost of the installation is in the order of $800,000. We consider this machine to be a prototype, to be versatile, and to prove out many more concepts which may be useful than more specialized machines that maybe don't cost $800,000.

EVALUATION OF THE STRUCTURAL INTEGRITY OF PNEUMATIC TIRES BY HOLOGRAPHIC INTERFEROMETRY

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ABSTRACT

Holographic interferometry, a versatile new method for high accuracy nondestructive testing (HNDT), has been developed and put into practice to reveal hidden anomalies and the lack of structural integrity in pneumatic tires. Coherent light is used in recording and reconstructing three-dimensional images and light interference fringe patterns. Through mild stressing (application of a vacuum) of the tire, subsurface anomalies are manifested in the form of minute surface displacements. These displacements reveal anomalies as small as a 1/16 in. in diameter in typical pneumatic tires. The interferometric pattern, produced by the surface displacement caused by the vacuum, is easily apparent and clearly indicates the location, size and shape of the anomaly. A brief explanation of the theory of HNDT, along with a variety of practical examples, is given in this paper. Emphasis will be placed on a discussion of the relationship between the anomalies observed in a variety of pneumatic tires, particularly truck tires, and the performance or the service given by the tires.

GENERAL DESCRIPTION OF HOLOGRAPHIC NONDESTRUCTIVE TESTING (HNDT)

Holographic interferometry combines both three-dimensional laser holography and laser interferometry into a powerful NDT technique not only able to detect material defects (subsurface voids, debonds, inclusions, etc.) but also to measure significant strength-of-material properties (strain, deformation, yield, creep, etc.).

Holography is a two-stage process that permits the reconstruction of three-dimensional images. A hologram of an object is formed in the first (recording) stage as shown schematically in Figure 1a. The complex optical wavefront reflected from the object is superimposed on either a spherical or a collimated reference wavefront. The optical superposition of these coherent wavefronts is recorded in a high-resolution photographic emulsion. Without the reference wavefront, the photographic emulsion would record only the intensity distribution of the reflected wavefront, without the phase information (as in conventional photography). Both amplitude and phase information related to the complex object wavefront are recorded, however, by the optical combination of the object and reference wavefronts throughout the region of space occupied by the photographic emulsion: the recording of the resulting two-beam interference pattern comprises the first stage of the holographic process.

A hologram (the developed photographic emulsion which is really a three-dimensional recording of an interference pattern) has the unique property that when illuminated by a wavefront similar to the reference wavefront used in the original exposure, diffraction in the hologram recreates the object wavefront (Figure 1b). An observer, therefore, looking through the hologram in the right direction can see a true three-dimensional image which is an exact replica of the object in size and in position relative to the plate.

Holographic interferometry is based on the fact that the reconstructed holographic wavefront does contain phase information so that two or more simultaneously reconstructed wavefronts can be compared. In this respect, the reconstruction stage can be likened to a three-dimensional Michelson interferometer. In a conventional Michelson interferometer, displacement of a movable mirror with respect to a stationary reference mirror changes the optical path length and, hence, induces an interferometric-fringe pattern from which the displacement of the movable mirror can be determined.

Suppose, now, that two holographic recordings of the same object are made in a single photographic emulsion with the object having been slightly deformed between exposures. When such a hologram (containing data about two wavefronts that did not occur simultaneously in the recording process) is reconstructed, the two wavefronts are simultaneously recreated. An observer is thus presented with a set of fringes superimposed over the image of the object

in which the spatial frequency of the fringes provides precise recording of the magnitude of the deformation of the object. That is, the precise magnitude of the difference in body shape or topology between the original and second states of the object is recorded holographically.

This holographically created optical interference permits the comparison of any object in two or more different stages that may have existed at different times in the past.

A specific deformation of an object, as a result of a particular loading, produces a unique holographic-interference pattern over the object surface, down to a few microinches, which can be measured without difficulty. Since each fringe relates to the deformation of the surface, variation in the geometry of a fringe is directly relatable to the topology or shape of the surface. The variation in the shape of the surface depends, of course, on the manner in which the object is deformed under load. The deformation of the object depends on the significant structural strength-of-material properties as well as on the defect characteristics of the object. Therefore, information about these properties and characteristics can be directly obtained from the holographic-interference patterns. All these comments will become much clearer after we have discussed a few specific examples.

EQUIPMENT AND TECHNIQUE FOR HNDT OF PNEUMATIC TIRES

Holographic interferometry can compare the surface of a tire in two or more different states. Since only the surface can be observed in the visible-light portion of the optical spectrum, it is essential that the tire be loaded or stressed in such a way that subsurface defects (separations, voids, etc.) and structural properties (splices, etc.) are exhibited on the surface as localized displacements.

Figure 2a shows a photograph of an experimental Holographic Tire Analyzer (tests about 6 to 8 truck tires per hour at a cost of about $3 per tire) which consist of (a) pneumatic, servo-controlled, vibration-isolation system and surface plate (Figure 2b); (b) the tire holding fixture (Figure 2c); and (c) an overall vertical view of the optics package showing a spread tire in place (Figure 2d).

The testing technique involves enclosing an unrimmed tire with beads separated in a vacuum chamber. The tire sits on a turntable or merry-go-round where one-fourth of the tire is tested at a time.

The stressing/holographic sequence consists of applying a partial vacuum and making half the holographic exposure, then venting to atmospheric pressure and making the remaining half exposure. The optics for forming the hologram are positioned so that they record an image of one-fourth or 90 deg of the inside of the tire from left ro right and from bead to bead -- top to bottom.

In the reconstruction of the hologram, the interferometric fringes are observed superimposed on the image of the inside surface of the tire. These fringes or bands are related to the change in shape of the tire surface. A distinct change in the shape of the fringes is noticed where anomalies are present under the tire surface. This characteristic pattern serves to locate the anomaly.

There are several features that make this technique extremely effective in tire anomaly detection. Only a minimal vacuum, less than 1 psi below atmospheric need be applied. In addition, since the anomaly size and depth detected is related to the amount of vacuum applied, there exists a possibility for sensitivity control and inspection for only those anomalies above a given size.

By inspecting from the inside of the tire, the detection sensitivity is enhanced due to the positive curvature of the tire with respect to the hologram. When the vacuum is applied, the air within the anomaly expands and causes the material between the anomaly and the tire's inner surface to bulge toward the surface.

The amount of overall deformation (or stretch) of the tire is small using this technique thus reducing the background fringe pattern making the fringes that record the anomalies more readily discernible. The fringes in the background, independent of the anomaly, are caused by the overall dilation or stretch of the tire brought about when the atmospheric pressure surrounding the tire is reduced. The air inside the tire, dispersed throughout, remains at atmospheric pressure for a reasonable period of time, thus bringing about the general overall dilation of the tire.

REPRESENTATIVE RESULTS

This section presents photographcs of typical reconstructed holograms showing tire defects and structural features.

For example, note the photograph in Figure 3, which shows two separations, one a 3/4-in. by 1/4-in. tread separation and the other a 1/2-in. by 3/4-in. shoulder body to carcass separation. Figure 4 is a photograph of the cut tire revealing the location of the separations.

Figure 5 is a typical photograph of a hologram containing both inner ply and belt-edge separations. Figure 6a, on the other hand, is a typical example of a broken glass belt (many individual cords have already severed) where some

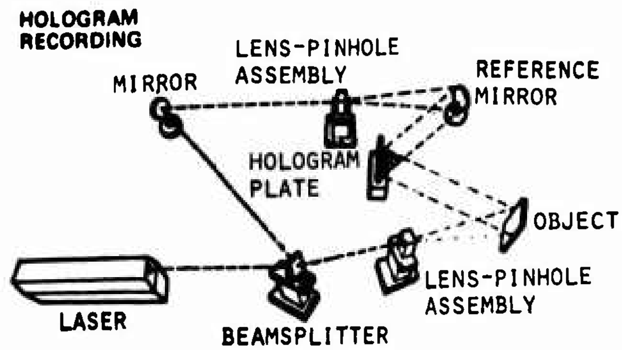


FIGURE 1a
HOLOGRAM CONSTRUCTION PROCESS

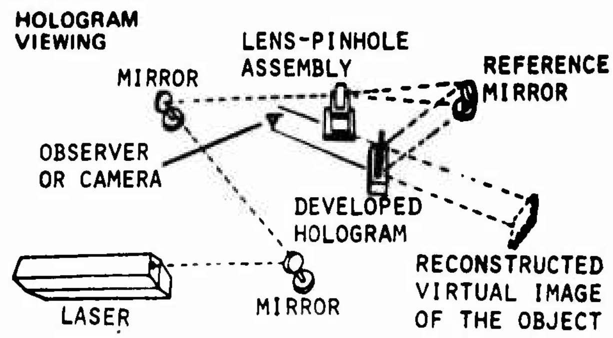


FIGURE 1b
HOLOGRAM RECONSTRUCTION PROCESS

The operating principle is based on holographic interferometry. Using a safe, low-power laser for illumination, a double-exposure hologram is made of a portion of the inner surface of the tire. One exposure is made with the tire subjected to a partial vacuum and the other at atmospheric pressure. The hologram constitutes a permanent record of the test.

After developing the film and reconstructing the image, an interference fringe pattern is observed. It shows the location, and in some cases, the type of many anomalies that occur in tires.

FIGURE 2a
HOLOGRAPHIC TIRE ANALYZER

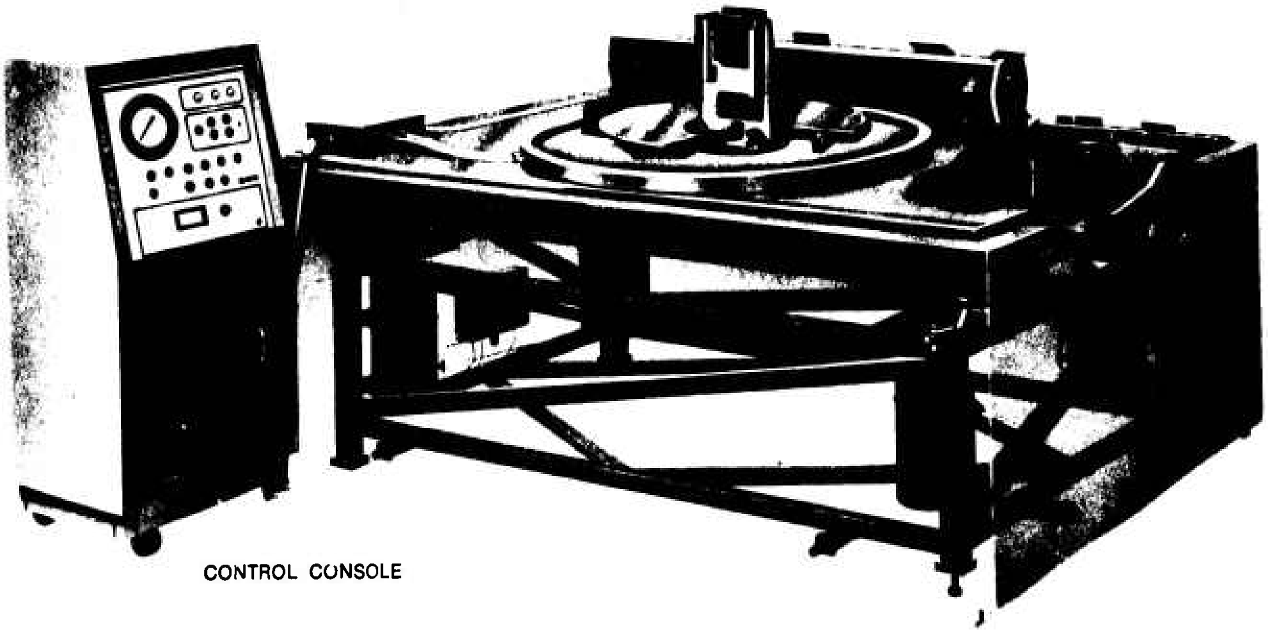


FIGURE 2b
CUTAWAY DRAWING SHOWING A PNEUMATIC SERVO-CONTROLLED VIBRATION ISOLATION SYSTEM

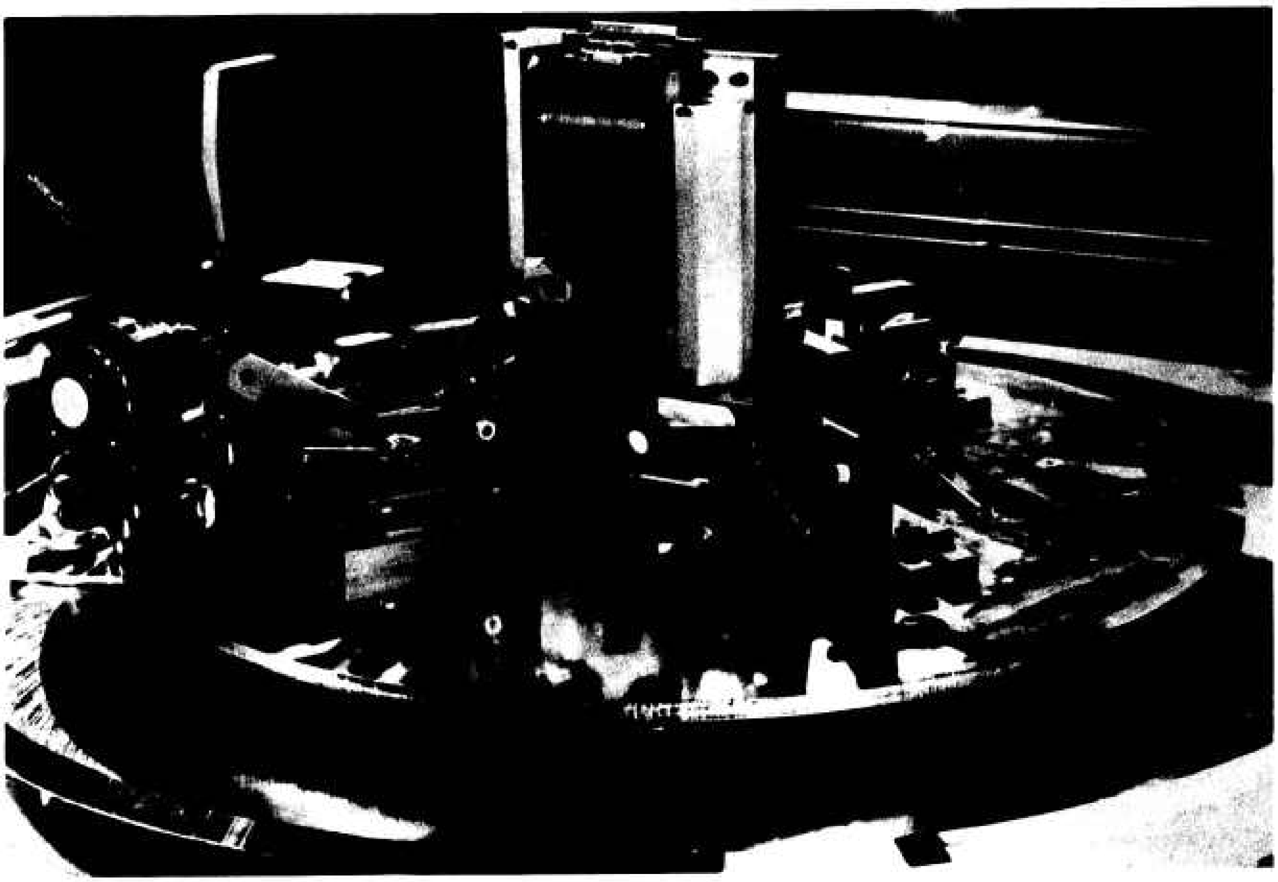


FIGURE 2c

FIGURE 2d
OVERALL VIEW OF OPTICS PACKAGE SHOWING SPREAD TIRE

RESULTS – The photographs below show what an inspector of holograms sees and how the data is interpreted in terms of a tire anomaly. In Figure 3 the two regions of highly concentrated fringes indicate the presence of anomalies within the tire at these locations. The background fringe pattern is caused by the general motion of the tire due to application of the vacuum.

Characteristics of these fringe patterns plus the known vacuum level and tire type leads to the prediction that we are seeing a tread and shoulder separation. A view of the tire, cut open at the location determined from the hologram, is shown in Figure 4. The tread (TS) and shoulder (SS) separations are indicated by the arrows.

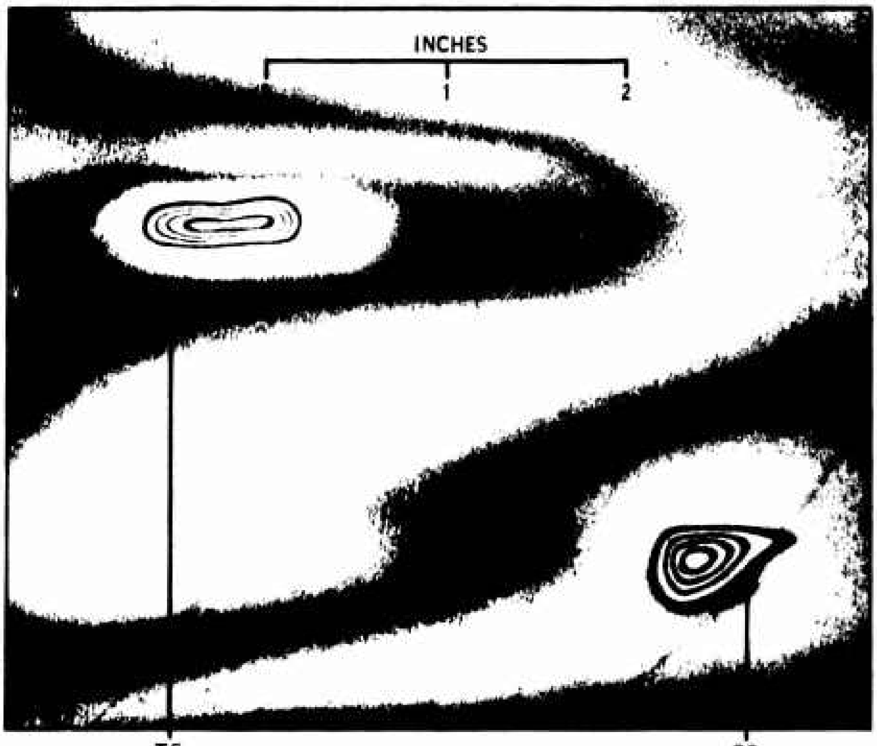


FIGURE 3
FRINGE PATTERN WITH IRREGULARITIES AS SEEN THROUGH THE HOLOGRAM

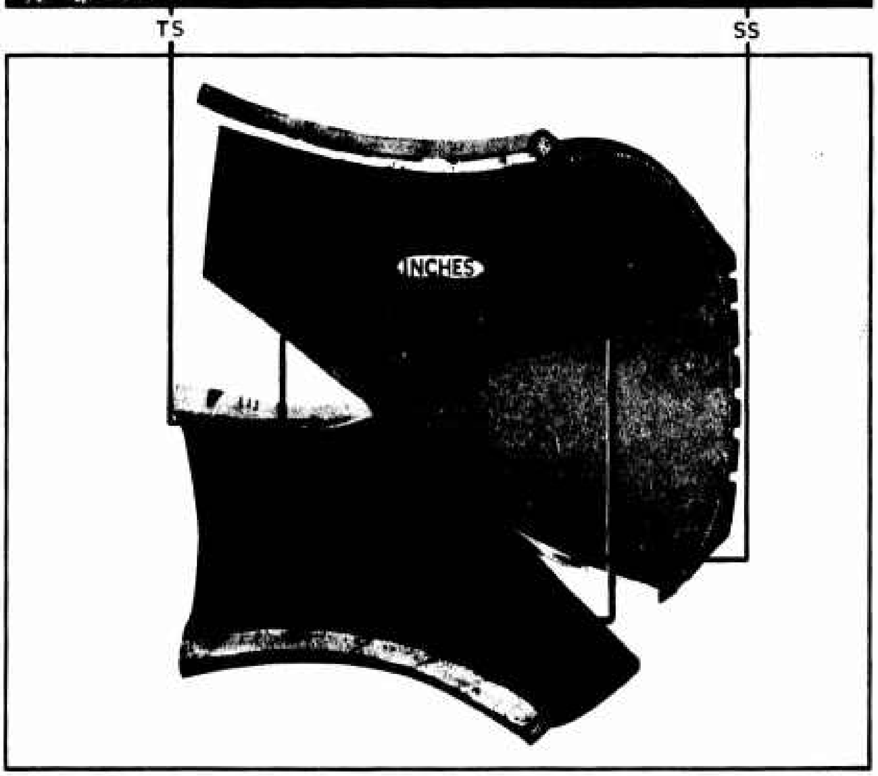


FIGURE 4
TIRE ANOMALIES LOCATED

regions have already propagated to the stage where they appear as inner ply separations.

In Figure 6b, a photograph of a hologram (boxed area only) is shown which clearly indicates the region of failure 107.5 mi before the failure occurred. The tire in this case had a total mileage of only 409.5 mi (test wheel data). Figure 7a shows typical inner ply separations in a 10.00x20 truck steel-wire-radial tire and a conventional nylon cord passenger tire (Figure 7b). Figure 8 is a photograph of a typical broken glass belt.

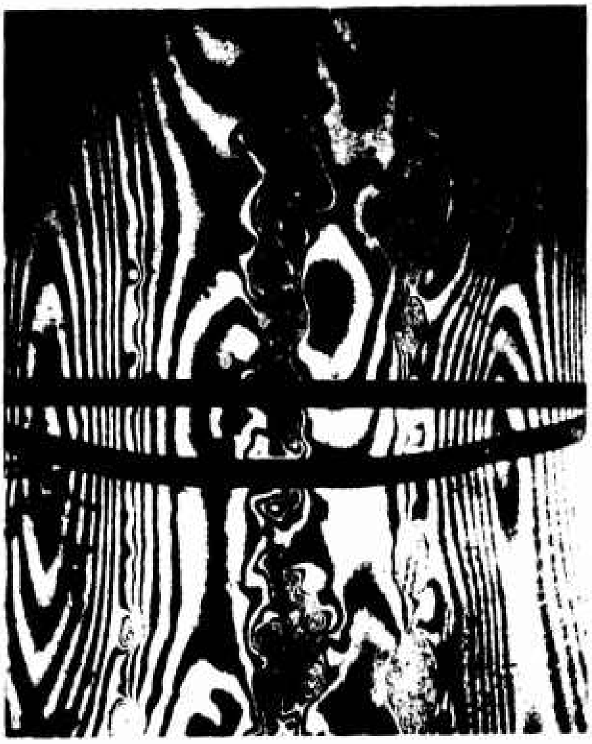
REPRESENTATIVE TEST RESULTS – PASSENGER TIRES

Prior to presenting some representative test results it is important to point out that over the past three years, while using the vacuum method of separation detection explained in this paper, the author has tested considerably more than 1000 tires. I have cut or have personally observed the cutting of over 100 tires which had holographically indicated inner ply separations. In no single case have I observed a holographically indicated inner ply or belt edge separation of 1/8 in. or larger which was not verified by destructive test. As a matter of fact, there is fair verification for separations in the 1/16-in. range. Below 1/16 in. the results become very questionable. It is, however, questionable whether such small anomalies are meaningful, especially when we have seen cases where even the 1/8- to 3/16-in. anomalies did not lead to failure in the field after considerable mileage.

Before making any comments about the meaning of inner ply separations we might ask the question: How many inner ply separations occur in a random sample of new passenger tires? In a study carried out in the summer of 1970, which we shall call Case I, the following results were obtained. There were 140 new rayon carcass, glass-belted tires (all the same size) randomly selected from various manufacturers in sets of 15 to 20 tires per set. In all cases no separation smaller than 1/8 in. in diameter was recorded. In the 140 tires a total of 147 separations were recorded. Of these separations 91 percent were less than 1/2 in. in diameter, and 9 percent were greater than 1/2 in. in diameter. Seventy-six of the tires, or 54 percent, contained all the separations noted, and the remaining 64, or 46 percent, had no separations.

The largest observed was 1-1/2 in. in diameter (there were two of these in the 140 tires). In the worst set, 15 out of 17 or 88 percent of the sample contained one or more separations, and a total of 51 separations were noted in the 15 tires. The largest number of separations in a single tire was seven.

FIGURE 5
TYPICAL PHOTOGRAPH OF HOLOGRAM CONTAINING (a) INNER PLY SEPARATIONS AND (b) BELT EDGE SEPARATION. Note Figures 5a and 5b which are photographs of the corresponding cut tire.



6a

6b

FIGURE 6
THE HOLOGRAPHIC PATTERN AT THE LEFT (BOX SHOWN AT RIGHT) CLEARLY INDICATED THE SPECIFIC REGION OF FAILURE 107.5 MI BEFORE THE FAILURE OCCURRED.

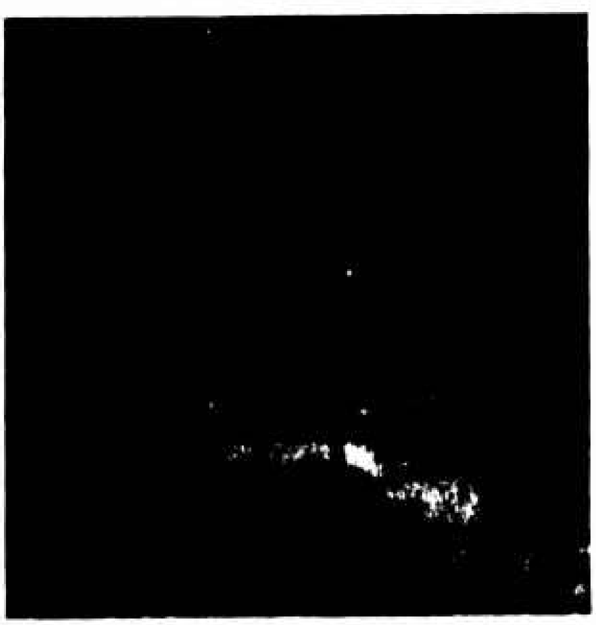


FIGURE 7a
EXAMPLE OF 3 in. DIAMETER INNER PLY SEPARATION IN A 10.00 X 20-STEEL WIRE, RADIAL TRUCK TIRE

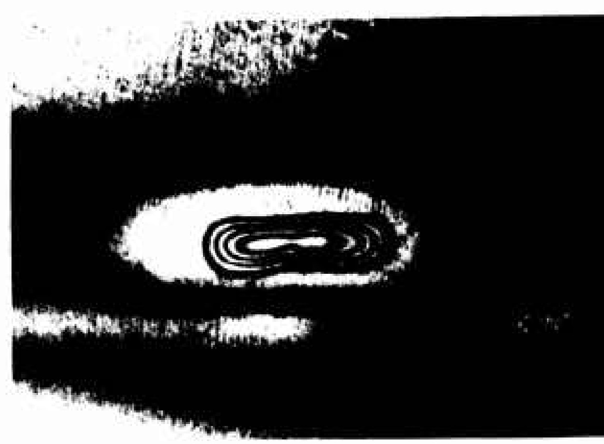


FIGURE 7b
TYPICAL EXAMPLE OF INNER PLY SEPARATION IN PASSENGER TIRE

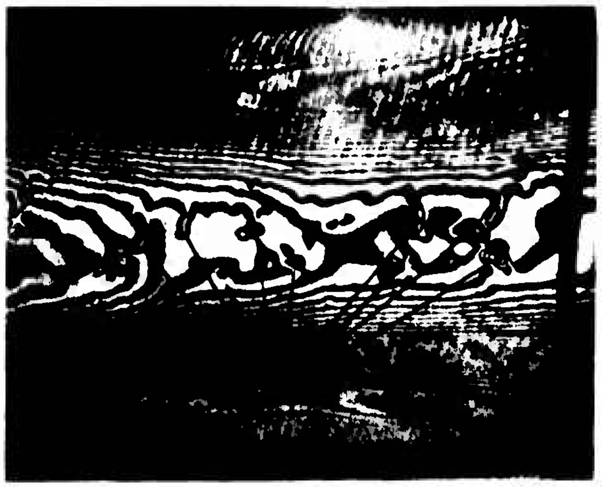


FIGURE 8
TYPICAL EXAMPLE OF A BROKEN GLASS BELT WHERE SOME REGIONS HAVE ALREADY PROPAGATED TO THE STAGE WHERE THEY APPEAR AS INNER PLY SEPARATIONS

In another study, Case II, 118 new tires were sampled (3 manufacturers, G78 15's, G78 14's, F70 15's, H78 15's). Here we observed 141 separations in 61 tires where they ranged in size from 1/8 in. to 3 in. Hence, 52 percent of the tires contained all the separations.

I could go on and report quite a number of such studies carried out under the author's direction; however, a conclusion was reached after an incredible amount of data had been gathered that the percentage of separations in passenger tires, including radial and bias belted, could vary anywhere between near 0 to 80 percent depending on the type of tire. On the average we observed 50 ±40 percent for bias belted tires and 10 ± 10 percent for radial tires. The above only implies, in my opinion, that separations are numerous in bias belted tires; however, the data is not overly meaningful.

If this many separations occur, it is obvious that many of them are not meaningful in the sense that they lead to failure on the road.

Let us now define a separation as an "anomaly" and furthermore define a "defect" as an anomaly which has been proven to be related with a high degree of probability to a failure in the field.

One would suspect at this stage that only the very large anomalies are truly defects. Now comes the dilemma! We have observed cases in road tests where small defects have led to failure and cases where large ones did not. We have, on the other hand, observed, as you might expect, cases where large defects led to failure and small anomalies did not. One can only conclude at this stage that our results are only preliminary and that much more study needs to be carried out.

At this stage, it would appear, due to subsequent work, that the classification of a separation as an "anomaly" or a "defect" depends very much upon its geometrical position and the design or type of tire. Note, for example, the suspicion (based on a single test of 24 tires) that a small belt-edge separation in a rayon carcass, glass-belted tire may cause a failure more readily than a larger crown separation; whereas in a radial tire the above does not appear to be the case at all!

It is quite obvious, based on Case A, that if 54 percent of all rayon carcass, glass-belted tires contained failure-related defects, the expressways in this country would be inundated with people changing tires, which obviously isn't the case. One might conclude, based on warranty data, that only a small percentage of the anomalies actually are defects which will propagate to failure.

It is clear from our data that some defects do propagate to failure early in the life of a passenger tire. Before concluding this section on passenger tires, note a few examples of anomalies which proved to be defects.

Belt-Edge Separation - Propagation Study -- To determine the general characteristics of the propagation of belt-edge separations in passenger tires, a series of tests was carried out on passenger cars where recommended tire inflation pressures were maintained. The vehicles were all driven under normal highway conditions. At no time during the tests were excessive speeds reached. The belt-edge separations were induced in the tires by the Automotive Test Center in Nevada*. All of the induced separations ranged from 1/8 in. to 3/8 in. The original tires were purchased from a regular sales outlet; however, we knew ahead of time that the level of warranty adjustments on this particular tire was running well above normal.

The tires were all holographed initially and re-holographed every 500 mi to study the mode of propagation of the belt-edge separation. Figures 9a through 9g are photographs which were taken upon completion of the tests.

*The author would like gratefully to acknowledge the expert assistance of Mr. Henry Hodges of the ATC in Carson City, Nevada, along with Mr. Robert Keyes.

Out of nine tires with induced belt-edge separations prior to road test (as verified by holographic tests), six were removed as failures from a significant growth of the holographically identified separated areas prior to 10,000 mi; two were removed as bead failures; and one completed the 10,000 mi test without external visual evidence of failure. This last tire, upon being cut, showed considerable growth of the separations within the 10,000 mi test.

A brief comment should be made about these two unusual bead failures. Since we mounted and dismounted the tires every 500 mi (the average tire was mounted and dismounted an average of 15 times), we are of the opinion that the beads were mechanically damaged during the frequent dismounting.

A brief summary of the seven tires is included in Figures 9a through 9g. In conclusion, failure of the tires was predictable in each of the seven cases. The control tires, those which did not contain anomalies, performed as expected without failure.

Despite the interesting results above, we still do not have enough "overall general data" to answer the question, "Are inner ply separations, in general, significant?" In the earlier examples pointed out, it would appear that many of the small separations are not significant. Yet, in the more extreme test just cited, the induced belt-edge separations were indeed significant. Much additional research needs to be done in this area.

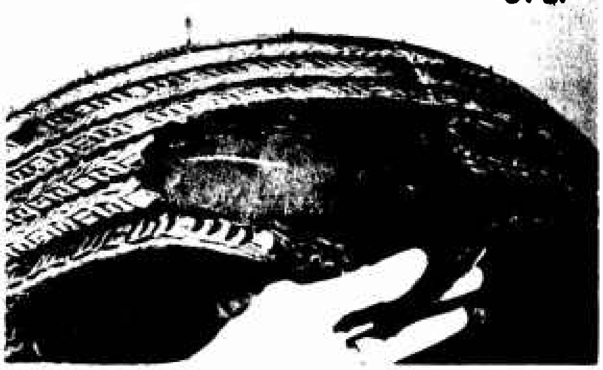
Finally, results to date indicate that the various sizes and types of inner ply separations for each individual tire design must be individually studied to establish a general set of rules relating to their meaningfulness.

9. a.

Tire removed from vehicle at 8001 mi due to 2 1/2 in. x 1 1/2 in. tread chunk-out caused by a belt edge separation between the carcass and the belt. Tire position RR 5500 mi, RF 2501 mi.

FIGURE 9a

9. b.

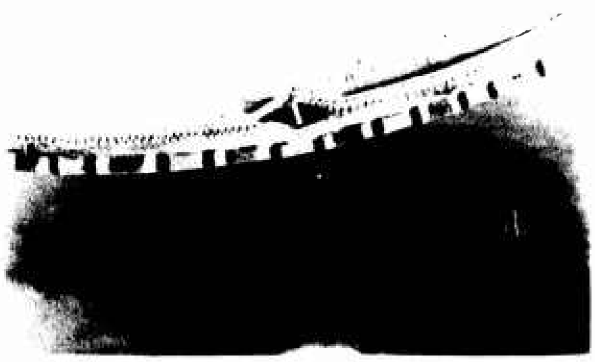


Tire removed from vehicle at 451 mi due to belt edge separation – chunk-out 8 in. x 3 in. Tire position LR 451 mi.

FIGURE 9b

Tire removed from vehicle at 10,000 mi. Tire contained two large crown separations. Belt edge separation masked out by heavier belt break up in the crown. Tire position RR 9000 mi, LF 1000 mi.

FIGURE 9c



Tire removed from vehicle at 10,000 mi. Cutting revealed a 1 in. x 1/2 in. separation in the belt edge between the belt and the carcass and random belt break up in the crown, but this separation was not in the location of the original belt edge separation. Tire position RF 3500 mi, RR 6500 mi.

FIGURE 9d

Tire removed from vehicle at 7785 mi due to failure. Cutting revealed 5 in. x 2 in., 2 in. x 1 in. and 1/4 in. x 1/4 in. belt edge separations and belt break up in the crown. Tire position LR 1250 mi, LF 6536 mi.

FIGURE 9e

Tire removed from vehicle at 10,000 mi without visible evidence of failure. Cutting revealed a 3 in. x 3 in. separation at the belt splice, and a 2 in. x 1 in. crown center separation. Tire position LF 3000 mi, LR 7000 mi.

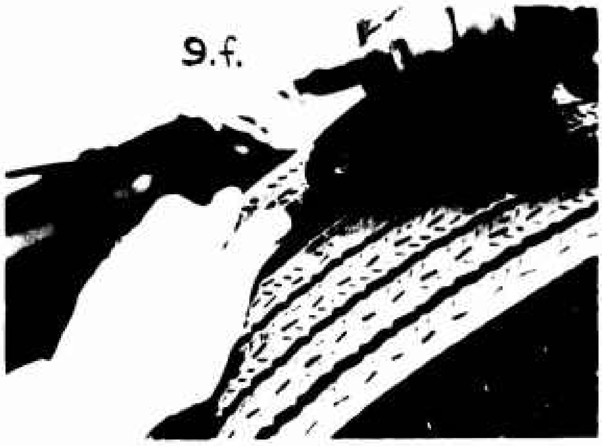


FIGURE 9f

Tire removed from vehicle at 5965 mi due to grove cracking and tread distortion indicating a large belt edge separation. Cutting disclosed a 12 in. long separation between the belt edge and the carcass from curb rib to crown center. Tire position LR 5965 mi.

FIGURE 9g

PRELIMINARY TEST RESULTS – TRUCK

Case I – In a study carried out last year in Detroit, Michigan, 300 tubeless bias-belted nylon-cord truck tires (10.00x22.5) were holographed, and about 225 were mounted on interstate highway trucks. Unfortunately, it was not possible to check these tires every 5,000 to 10,000 mi as is presently being done by the author in another study. The statistics gathered on these tires were as follows:

Sample			Approx* Percent	Tires
300	Reject	Outright rejection due to separations 1/8 in. or larger and extreme nonuniformity	25	75
	Mounted	Nonuniformity – extreme	50	225
		Nonuniformity – moderate	25	

Approximately 225 tires were running on trucks within the same fleet by the early summer of 1972. Within 90 days (under 10,000 mi/tire), the tires were recalled from the field due to over 50 failures out of the 225 tires. Moreover, the tires were at that time failing at the rate of two to five per day. Through excellent cooperation with the manufacturer of these tires, a new 10.00x22.5 was designed based on information gathered from both destructive cutting of tires and holographic data.

Approximately 270 tires of the new design were then placed on the trucks. The new tires were significantly improved as verified by holographic data. To date the tires have been running without noticeable failure.

Holographic studies clearly predicted that the original group of tires was grossly inferior. Apparently not only small inner-ply separation but holographically observed nonuniformity contributed as well to these failures.

It would be interesting to now go back and run the tires which were originally rejected. One of the holographic rejects was run on a test wheel, and, as expected, failure occurred very prematurely.

Case II – Again, to refer to studies carried out in Detroit last summer on local trucking fleets with tires manufactured by one of the leading foreign manufacturers, we gathered the following general data (over 1000 truck tires were tested all together); please refer to Figure 10.

The chart is self-explanatory except for the meaning of the results. It is important to point out that only extreme cases are shown in this chart. Many other samples were

*Approximate, because some tires had both inner-ply separations and holographic nonuniformity (the holographic rejects were returned to the manufacturer). Most of the rejects contained separations in addition to extreme nonuniformity as observed holographically. Small separations existed in the 225 tires which were mounted.

Size and Type	Sample – No. of Tires Observed in Study	Tires Containing Separations* and Very Poor Uniformity	Outright Holographic Rejects, %	Poor but Passed, %	General Comments	Detroit Field Results Based on Approx 1000 Tires
10.00x20 Nylon Cord Lug. Type Drive Axle	94	31%	22	20 - 40	Overall quality as holographically judged – poor; many poor tires passed	Over 25% of the tires sold failed prematurely within 50,000 mi
9.00x20 10.00x20 Steel Wire (Radial)	116	4% Seps. only	4	0	One 4" separation; Uniformity – excellent; Overall quality excellent	No failures after 50,000 mi
10.00x20 Nylon Cord Steering Axle Tire	32	10% Seps. 5% Nonuniformity	15	0	Overall quality excellent	No failures after 40,000 mi
10.00x20 Nylon Cord Trailer Axle Tire	92	Seps. 1/2"-2 1/2" 9% Seps. 1% Nonuniformity	10	2 1/8" Seps.	Overall quality very good	Failures under 1/2% – 50,000 mi

*Separations over 1/8 in. diameter – typical separation found 1/8 to 1 in.

FIGURE 10
CASE II – TRUCK TIRE STUDIES

made where the average percentage of rejection was well under 5 percent. Further, note that to date we don't know exactly where to set the rejection criteria. In some cases we have been too harsh and in other cases too lenient. In the case of the 10.00x20 lug based on our sample of 94 tires, it was obvious that we passed too high a percentage of the questionable tires resulting in a loss of over 50 out of the first 200 sold in one dealership alone over a 6-mo period. We should have rejected as much as 50 percent of the shipments of this tire. One thing was certain, the climax for the foreign manufacturer in the Detroit area was beyond estimation. We could have avoided the embarrassment had we rejected more, since the manufacturer, as all manufacturers I have talked to, was quite willing to credit us for the holographic rejects prior to sale of the tires.

On the other hand, the rejection rate of the 10.00x20 steel wire radial was probably too severe. Small 1/4 in. to 1/2 in. separations in a radial probably are not as serious as they are in a bias-belted truck tire due to cooler running conditions. Typically, less than 1 percent of the tires are highly questionable.

Thirdly, the rejection rate of the steering tire may also have been too high; however, no compromise should ever be made on a tire to be placed in a steering axle position.

Lastly, the trailer axle tire rejection rate is probably just about right for this tire; however, by rejecting the 1/8 in. separations the overall failure rate might be reducible from 1/2 to near 0 percent, disregarding, of course, road hazard adjustments.

It would appear at this stage that inner-ply separations and nonuniformity are much more significant in truck tires than in passenger tires because of the much higher sustained running temperatures.

Based upon an overall sample of approximately 1000 truck tires tested to date, I would make an early prediction that well under 1 percent of the radial truck tires need to be rejected. On the other hand, it would appear that bias-belted truck tires need to be watched more closely, resulting in rejection rates of from 1 to 4 percent. Only in extreme cases, such as some of those given in Figure 10, would a given tire type experience a reject rate above 5 percent.

COMMENT

Before concluding, I would like to make a very brief comment on the personal experiences I have had with the rubber industry while traveling around the world over the years explaining and discussing holographic testing. I have been very deeply impressed with the objectivity and sincerity of these people in their desire to produce products of outstanding quality. Almost every major tire manufacturer – in Japan, Europe, and in our country – has in some way or another supported research in holographic nondestructive testing of tires. Goodyear and Firestone along with Uniroyal and General have all made significant contributions in this area.

As a result of these experiences I have a great deal of faith in the future of this field of the nondestructive testing of tires. It will take a number of years to solve the basic NDT problems of this industry, but we can be sure that they will provide excellent encouragement and support. I never cease to be amazed by the oustanding quality of the tires presently being manufactured by the Tire Industry.

CHAPTER IV — ULTRASONIC TIRE TESTING

INTRODUCTORY REMARKS

Gwynn K. McConnell
Naval Air Development Center
Warminster, Pennsylvania

The talks this afternoon on ultrasonics are primarily concerned with aircraft tires, and particularly addressed to satisfying the Navy requirement for nondestructive inspection of rebuilt tires. We will be talking about rebuilt aircraft tires, but the technology is applicable to all pneumatic tires.

Ultrasonic inspection methods have long been respected for versatility, simplicity, and maximum information content. Today we don't have all the answers in ultrasonics — you'll be the first to point that out to me I'm sure — but I will insist that we do have enough to permit some necessary work today. I want to preface the introduction of the first paper with a couple of remarks as to the Navy attitude towards separations. I was very glad to hear Dr. Grand say that among truck tires primarily he felt that separations were to be concerned about, whereas a lot of people are thinking about road vehicle tires where separations are not that significant. In aircraft tires they are significant, and they are quite often indicative of a number of things. We're talking about rebuilt tires; we're talking about degradation and related phenomena; we're also talking about sloppy rebuilding workmanship, and that does happen; we're also talking about original interply adhesion values that were low, and on the first rebuild the plies will separate. So, it's a little different thing, but it is a significant thing, and it has been documented to some degree. The criticality of separations in aircraft tires is being developed – that information is being worked on now. But we have run dynamometer simulated flights at Wright Patterson Test Facility on aircraft tires with built-in separations of 1/4 in., 1/2 in., 1 in. and, I think, 2 in. I will tell you that on certain size tires you can rebuild the tire, have a spec adhesion at the layers that you rebuild, and have quality material – and you can have a small separation of 1/2 in., and it will separate and that tire will fail and will not qualify. The present program is to collect as many samples as we can of natural flaws where the difference between them is that they are a low contrast specimen as compared to a high contrast specimen where you make a separation and have high adhesion values all around it. A "low contrast" natural separation will most likely have low adhesion values all around it.

Our first speaker in ultrasonics is Mr. P. T. McCauley, of James Electronics, Inc.

COMMERCIAL THROUGH-TRANSMISSION TIRE INSPECTION

P. T. McCauley, Vice President
James Electronics, Inc.
Chicago, Illinois

ABSTRACT

Basic design criteria for a commercial ultrasonic nondestructive inspection system are established.

Three ultrasonic techniques for satisfying these criteria are discussed, as are the reasons for selection of through-transmission as the technique for use in a commercial system.

Certain problems encountered in through-transmission testing are discussed, and the solutions to them are given. An adaptive, or self-calibrating scheme is described which compensates automatically for variations in transmission from tire to tire, and from one portion of a given tire to another.

A complete prototype system presently in commerical service is described.

There are two general classes of requirements which must be met by an ultrasonic nondestructive inspection system for tires if it is to be generally useful in commercial applications. The first of these may be categorized as the operational requirements: what is involved in using the machine in a typical industrial environment. The second is made up of the technical requirements: the ability to detect anomalies of interest with suitable resolution and accuracy.

In considering a commercially viable system, the two classes of requirements are of equal importance. There are several different laboratory techniques which yield a large amount of valuable information about the internal integrity of a tire. For the most part, an effort to apply these to a production situation is at best frustrating and costly. On the other hand, a piece of equipment which is well adapted to commercial service, but which does not yield sufficiently accurate and reliable results, is worthless.

The following minimum operational requirements were established for the design of a suitable nondestructive inspection system:

1. A test time, floor-to-floor, of 2 min for a moderate size tire.
2. Automatic operation for the actual test cycle.
3. Satisfactory operation by a semi-skilled operator having no previous ultrasonic testing nor electronics training.
4. Self-calibration.
5. A high degree of insensitivity to ambient acoustical and electrical noise.
6. An easily interpreted GO/NO-GO readout.
7. Modest cost, high reliability, and ease of maintenance.

The concomitant technical specifications are:

1. Detection and resolution of anomalies in plies or between carcass and tread having a diameter of 1/4 in. or more.
2. Indication of approximate size of anomaly.
3. Detection of cord breakage.
4. A permanently recorded output showing location of the anomaly in the θ and ϕ coordinates. The θ coordinate is the angular displacement from a reference point on the periphery of the tire; the ϕ coordinate is the angular displacement from vertical in the bead-to-bead direction across the tire.

Three ultrasonic inspection techniques were considered as offering possible bases for equipment design. The first of these is low-frequency pulse velocity measurement. In this technique a pulse of energy is transmitted into the material under test, and the time required for the pulse to propagate through the material to the other side is measured. For a known thickness and transit time, velocity of propagation is determined. This velocity is a function of the dynamic elastic modulus, the density, and Poissons' ratio for the material. For a given structure, it is essentially constant if the fundamental physical properties of the structure remain constant throughout.

Investigation showed that velocity was, in fact, substantially constant for a given tire, but, as might be expected, there were variations in velocity between different tires of the same type. For a given tire the apparent velocity changes when the pulse of ultrasound is caused to propagate through a region containing an anomaly. This apparent change occurs because the wave must propagate around the anomaly and, therefore, has a longer distance to travel.

In view of the small size of anomaly to be detected, variations in apparent velocity are uncomfortably close to the magnitude of experimental error. Therefore, use of this technique was ruled out. However, a considerable variation in amplitude of the received signal was noted when the transmitted signal was caused to propagate across an anomaly.

An adaptation of conventional pulse-echo testing was investigated. A substantial amount of research in this area has been conducted by others with excellent results. This technique is the subject of a paper to be given later today so it will not be discussed further here. Considering the requirements for rapid testing and a simple GO/NO-GO output, we concluded that the necessary signal processing would be unduly complex and costly for general production inspection use.

Goodyear Tire and Rubber Company published a paper on the results of through-transmission testing of tires in 1951. This work, coupled with a number of more recent reports, and our own observations of pulse amplitude attenuation led us to investigate through-transmission as the technique most likely to satisfy both operational and technical requirements. Most of the reports on the use of this technique note large variations in acoustic attenuation between different, good tires of the same type, as well as between tires of different types and sizes; sensitivity to ambient acoustic noise; interference from sound leakage, standing waves, and reverberation. Basically, the solution to these problems falls into two general areas. The first of these is adaptive control of system gain, or self-calibration. The second is control of signal-to-noise ratio.

The achievement of high signal-to-noise ratio requires that the maximum practical amount of ultrasonic energy be transmitted into the tire under test, with a minimum of leakage through other paths directly to the receiving transducer. To accomplish this, it was decided to use water coupling between the transmitting transducer and the exterior surface of the tire so that transfer of energy into the tire would be maximized. Using water coupling, ultrasonic energy which is not transmitted into the tire is dissipated within the water by reflection from the sides of the tank and from the surface of the water. Because of the very high mismatch in acoustic impedance between the water, tank walls, and the air, virtually no leakage of ultrasound occurs. The various reflections within the tank, of course, generate standing waves. The effect of these can be reduced to negligible proportions by the use of frequency modulation.

The receiving transducer, when positioned inside the tire, is shielded to some degree from ambient acoustic noise. To provide a further increase in signal-to-noise ratio, a comparatively high-powered CW transmitter is employed. Approximately 20 watts of acoustic power is radiated into the water by the transmitting transducer. The noise level, from all sources, in the output of the receiving transducer is several orders of magnitude less than the signal output. The achievement of this signal-to-noise ratio and a large absolute magnitude of output signal allows the use of a straightforward AGC system to provide adaptive gain control.

Figure 1 shows the engineering prototype of the tire handling and transducer positioning equipment. The tire is held by the inner bead by the arms of a modified Branick spreader which also rotates the tire in a clockwise direction when viewed as in the photograph. The interior transducer is supported by a removable arm to allow tire loading. Figure 2 shows the interior transducer removed for loading, and Figure 3 shows the exterior transducer.

Figure 4 shows the transducer positioning drive motor, programming cam, and the various drive linkages. The main shaft, on which the large sprocket is mounted, drives the exterior transducer. The small sprocket and chain at the right side provide drive to the interior transducer. The drive shaft may be seen extending into the base hub of the interior transducer support. At the near end of the shaft, at the lower right of the photograph, there is a transmitting potentiometer which provides angular position information for the transducers. The exterior transducer describes a circular arc about the outside of the tire, and the inner transducer follows so as to remain coaxial with it. The beam width of the transmitting and receiving transducers is about 30 deg so that an approximately 1 in. diameter spot on the tire is illuminated. Thus, when the tire is rotated, a strip around the periphery of the tire having a width of about 1 in. passes between the transducers.

Referring again to Figure 4, there is a programming cam immediately in front of the main shaft drive sprocket. Lobes on the cam determine the angular position for starting and ending a series of scans and the angular increment for each scan. The cam shown in the photograph provides ten 12 deg increments so that an included angle of 120 deg is scanned. This is adequate for most tires. As tire diameter becomes greater, spacing between the tire and the transducers increases proportionately, and a wider strip of the tire is scanned for each angular increment of transducer position. If greater resolution or a different angle is desired, the cam is easily exchanged for one providing the desired characteristics.

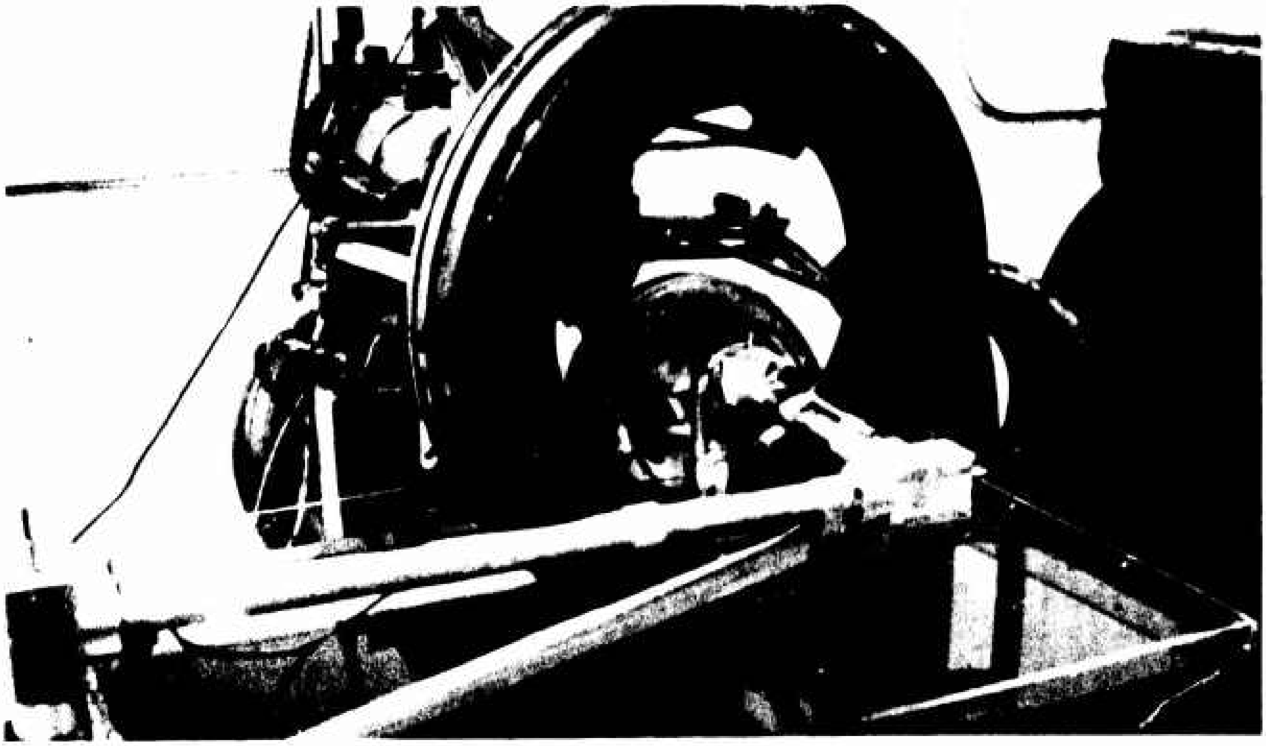


FIGURE 1

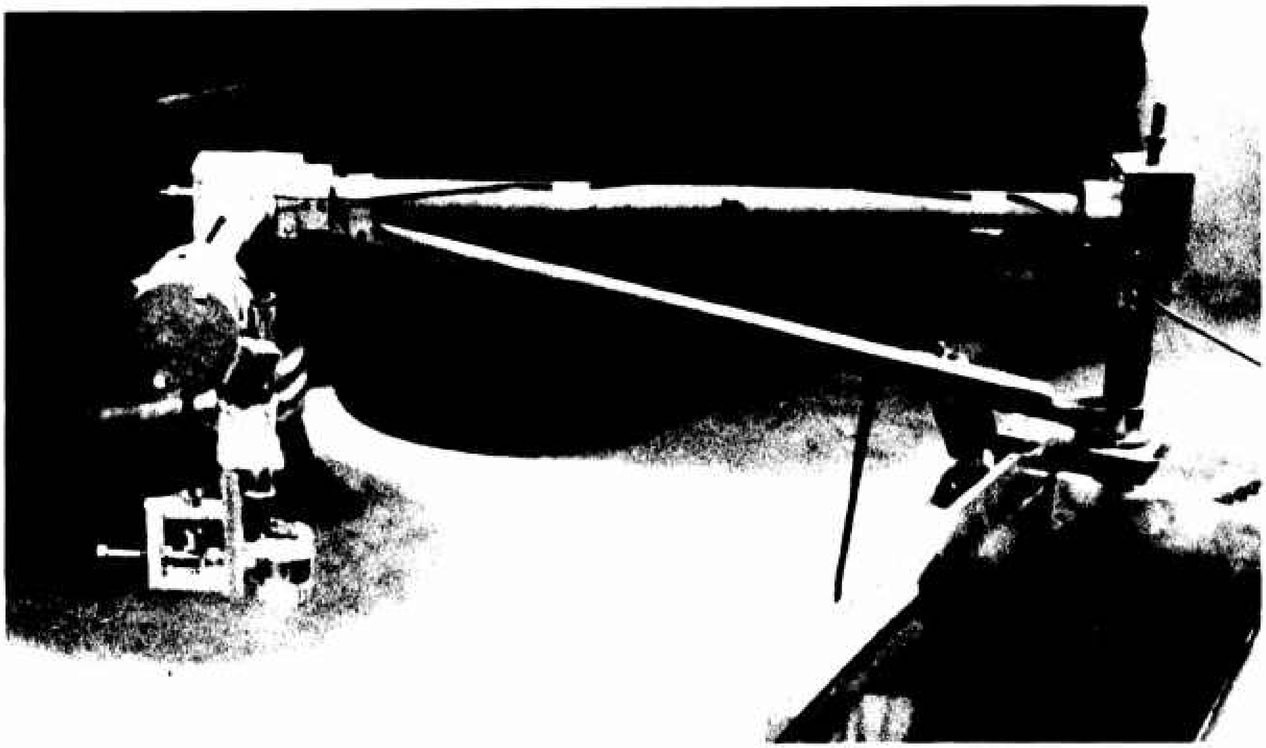


FIGURE 2

Figure 5 shows the electronics console which houses the control panel, the X-Y plotter used as a readout device, and the necessary electronic circuitry. It is interconnected to the scanner deck by cables, and may be positioned up to 30 ft away from the mechanical equipment.

Controls are provided for manual and fully automatic operation using pushbuttons mounted on the control panel. In the manual mode, speed of tire rotation can be adjusted from 0 to 20 rpm, and transducer positioning is continuously adjustable over an arc of about 170 deg. In the manual mode, the X-Y plotter indicates angular position of the transducers on the Y-axis and angular position of the tire on the X-axis, as well as level of sound transmission through the tire. Y-axis, or ϕ coordinate information, is derived from the transmitting potentiometer on the interior transducer drive shaft. X-axis, or θ coordinate information, is derived from a similar potentiometer mounted on the main shaft of the spreader. A control is also provided which is active in both manual and automatic modes and causes the transducers to return automatically to the vertical position for tire loading.

In the automatic mode, the transducers move out to the start position, tire rotation starts at 20 rpm, and on every second rotation the transducers change angular position by 12 deg (the increment being determined by the programming cam). At the finish of the last incremental scan, the rotation stops, and the transducers return to the load position, completing the automatic cycle. It was noted that the transducers reposition on every second rotation of the tire. During the alternate rotation, the X-Y plotter is enabled, and a plot of transmission through the tire is made. In this way time is allowed for plotter re-trace and transducer positioning without missing any of the tire surface.

At 20 rpm, 3 sec is required for a tire revolution. Thus, for ten 12 deg increments, or a complete scan, 60 sec is required. An additional 5 or 6 sec is required for transducer positioning at the beginning of the scan and return to the load position at the end of the cycle. Tire loading and unloading and insertion of paper in the plotter are manual functions. Typically, about 3 min is required to inspect a tire. Improvements in the tire handler and automatic feed for plotter charts are expected to reduce total time to the desired 2 min.

Figure 6 is a reproduction of a recording of a 26x6.6 aircraft tire containing simulated defects as well as two balance pads. A programming cam providing sixteen 10 deg increments was used in making this recording. You will note that a 1/4 in. separation gives a barely discernible break in the baseline, while 1/2 in. and 3/4 in. separations are clearly indicated. This equipment maintains this level of discrimination automatically over a range of tire sizes and types, and may be quickly checked by running a reference tire containing known defects.

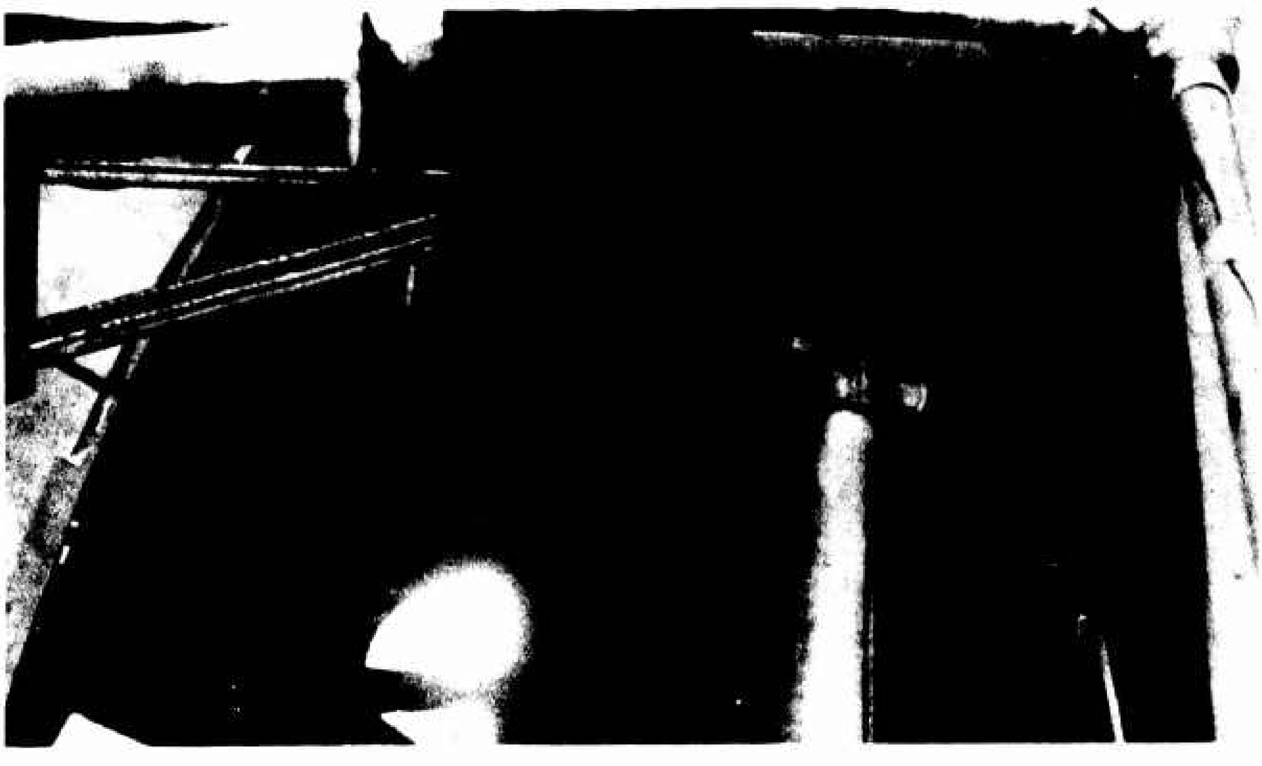


FIGURE 3

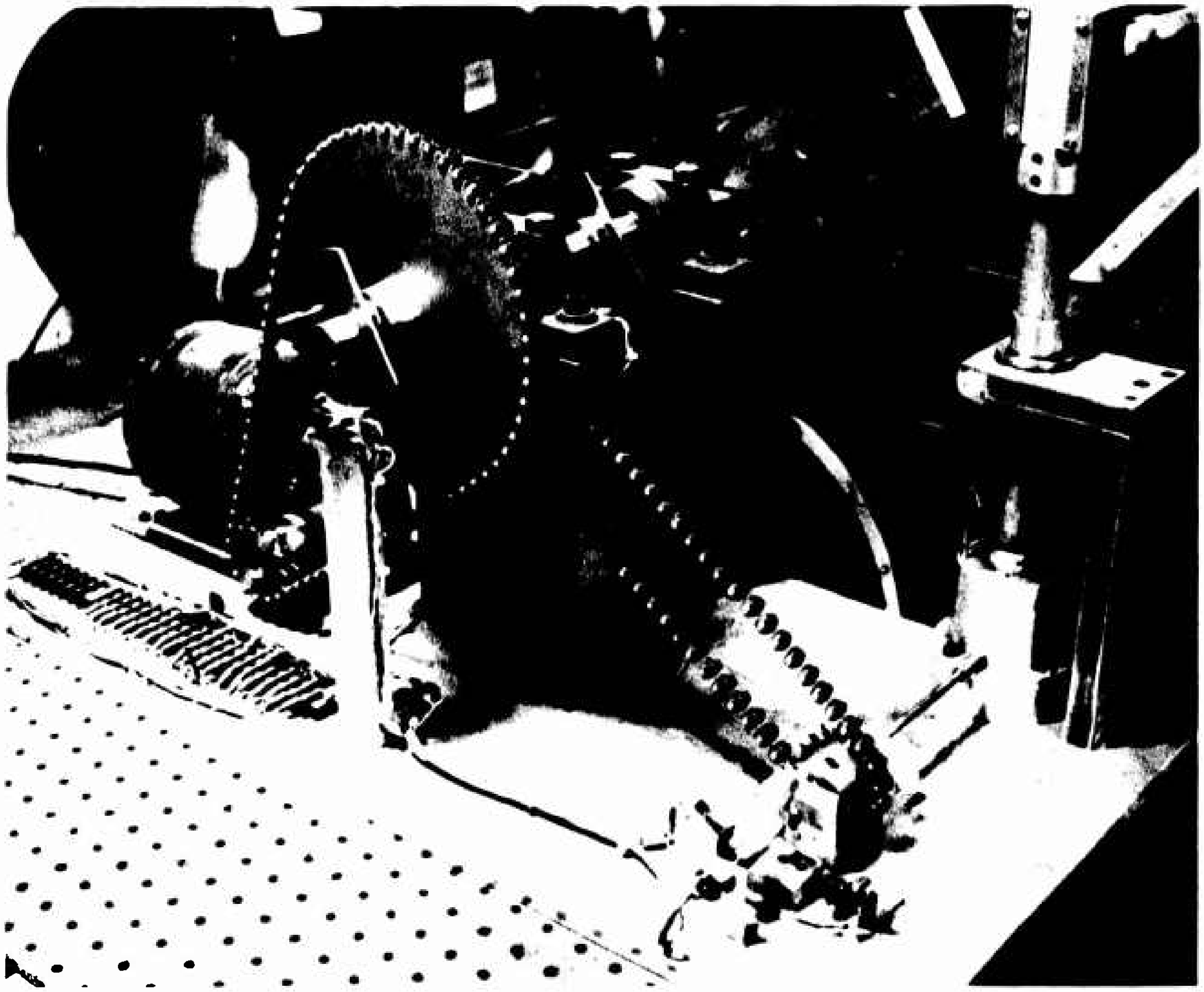


FIGURE 4

Remarks thus far have been directed to an engineering prototype model of the tire testing equipment which is in service at Bandag's facility in Muscatine, Iowa. Regular production use of this equipment for inspection of aircraft tires over a period of 4 mos. has indicated the need for certain changes.

As mentioned, an improvement in tire handling will decrease inspection time. Whether or not the use of automatic chart loading is economically justifiable is under consideration. The positioning mechanism for the interior transducer is rather complex. While it performs satisfactorily, it will not stand much abuse. However, of considerably greater importance is the elimination of water coupling to the exterior of the tire.

Earlier it was mentioned that water coupling had been selected as the best solution to the signal-to-noise ratio and sound leakage problems. An intensive program has been conducted over the past year to design a practical means of coupling ultrasonic energy into a tire without the use of water but with equivalent effectiveness. This has yielded several alternatives, of which a modified type of wheel transducer has produced excellent results. James Electronics is presently reducing the engineering prototype design of the nondestructive test system to a production unit which will have all of the same desirable characteristics without the use of water coupling.

In concluding, I wish to acknowledge the patient cooperation and substantial assistance received from Bandag, Inc. Without their enthusiastic and continuing support it is not likely that adaptation of our low frequency ultrasonic equipment to tire testing would have been successful.

FIGURE 5

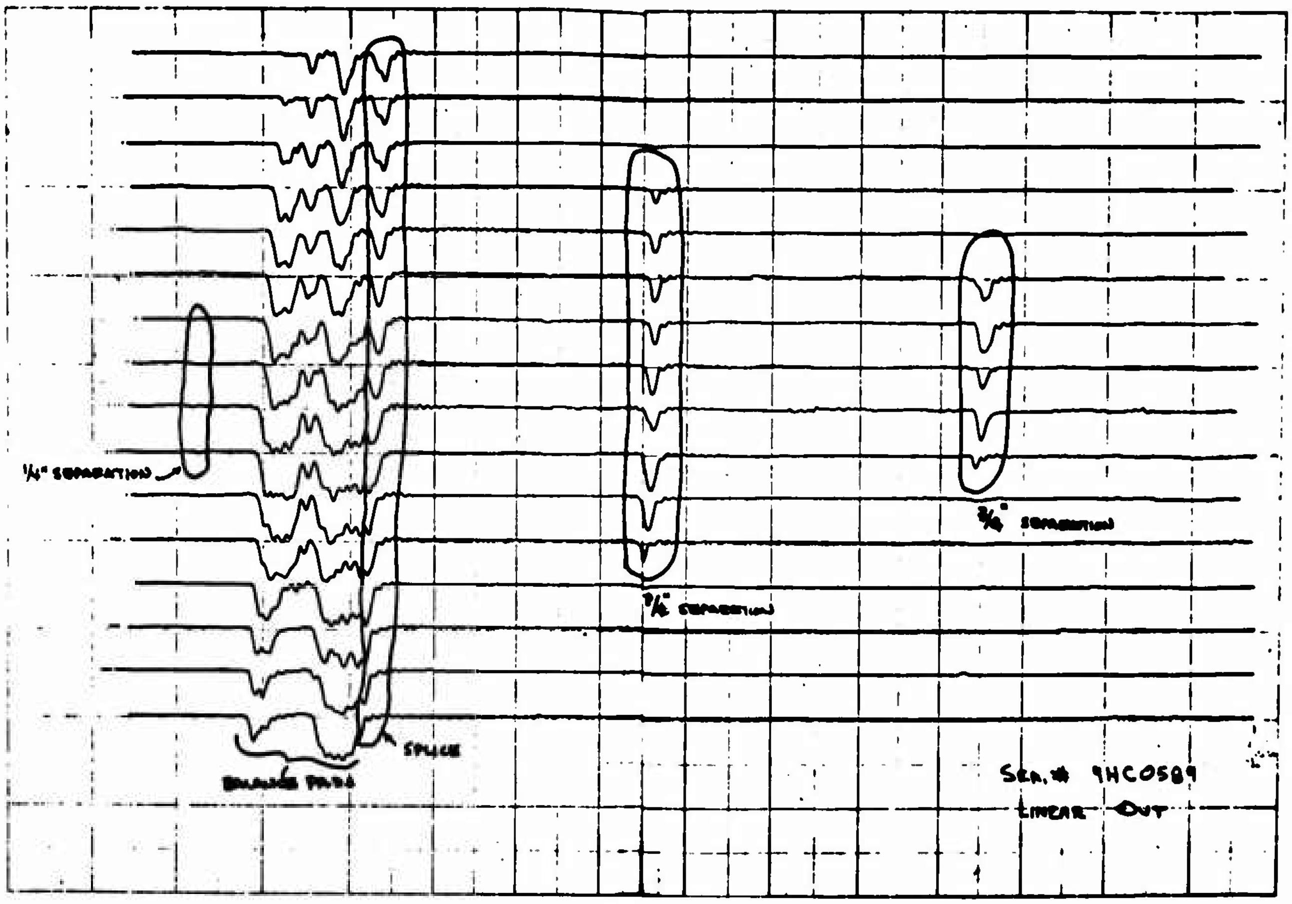


FIGURE 6

AIR-COUPLED ULTRASOUND AS A PRODUCTION INSPECTION TECHNIQUE FOR AIRCRAFT TIRES

H. E. Van Valkenburg
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Danbury, Connecticut

ABSTRACT

Low frequency ultrasound, e.g., 24 kHz to 40 kHz, is now being applied to a number of NDT applications problems not previously solved.

These include inspection of low density and "lossy" materials for laminations, lack of bond, and gross voids.

To provide suitable instrumentation a new product line, the SONDICATOR, was developed. Pulsed wave-trains and a variety of signal processing and readout techniques are used. Because of the relatively long pulse lengths at the frequencies involved, dual search units are required and either "through-transmission" or point-to-point pickup is employed. For low density materials, air coupling is reasonably effective so that contact with the test specimen can be avoided.*

One of the earliest and most successful uses was the detection of delaminations in plywood and particle board where only an air-coupled system was feasible.

Since experimental work on detection of tire separations also showed promise, fixturing was built for semi-automatic testing. Within our company, the most extensive production testing has been performed by our Australian group, Automation Sperry Pty, Ltd., where a commercial inspection service for aircraft tire retreads has been established using a multichannel SONDICATOR system with one transmitter and several receivers.

Through-transmission methods for ultrasonic testing have been extensively used for many years, especially for the detection of laminar flaws. Several typical applications are reported in the *Nondestructive Testing Handbook* (1959) including an early reference to rubber tire inspection by W.E. Morris (1945).

The transmission method depends on the decrease of signal resulting from the interception of the sound beam by discontinuities within the material, such as porosity, cracks, or laminations. Therefore, the area of defect to be detected must represent a substantial portion of the incident beam, usually at least 25 percent. Unlike pulse-echo systems, no depth information is derived, and the discontinuity detected could be located anywhere in the cross section. Only regularly shaped objects of uniform surface and thickness are generally amenable to transmission testing. Immersion coupling was almost always used to achieve uniform sound transmission.

During the last five years, dry or air-coupled sound of relatively low frequency (e.g., 25 kHz) has been effectively applied to a number of previously unsolved inspection problems including detection of unbond or blisters in sonically "lossy" materials such as plywood, particle board and low density composites. At these frequencies the long wavelength involved (e.g., about 2.5 in. in wood or rubber) further limits the minimum detectable area.

The basic technique (Figure 1) uses air gap coupling so that the transducers can be separated up to several inches from the surfaces, thus permitting "in-line" testing of materials that cannot tolerate liquid couplants. New instrumentation and search units, called the SONDICATOR line, have been developed to make optimum use of dry coupling methods.

These use pulsed wave-trains and a variety of display, signal processing, and readout methods. The initial tire studies were done with the Type S-1 SONDICATOR (Figure 2), which provides CRT display of signal amplitude and time, as well as gated output of amplitude or phase. Another model, the Type S-2B (Figure 3) which may be battery operated, was designed for portable use, particularly testing of aircraft honeycomb and laminate bonding; meter readout only is used. There are two basic search unit types (Figure 4), one for point-to-point contact measurement (right) and the others for noncontact air coupling (left). Typical waveshapes (Figure 5) illustrate the drop in signal over an internal discontinuity, such as a lamination, as well as the adjustable electronic gating step. Analog output proportional to amplitude is available for alarm or recording purposes. When combined with mechanical scanning, either C-scan or line-amplitude charts may be made (Figure 6).

*SONDICATOR is a trademark of Automation Industries Inc.

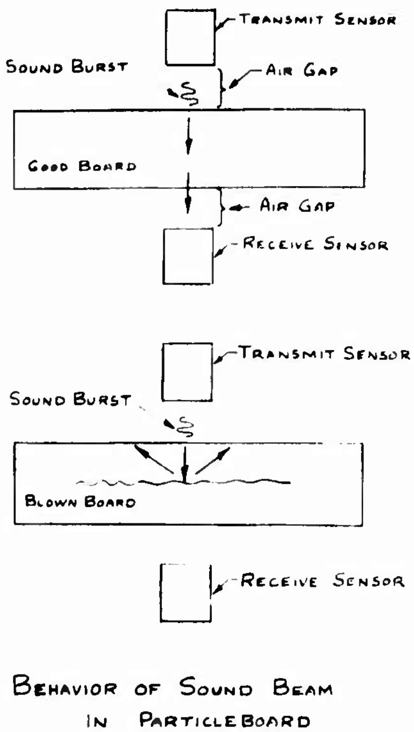


FIGURE 1
PRINCIPLE – THROUGH-TRANSMISSION TESTING

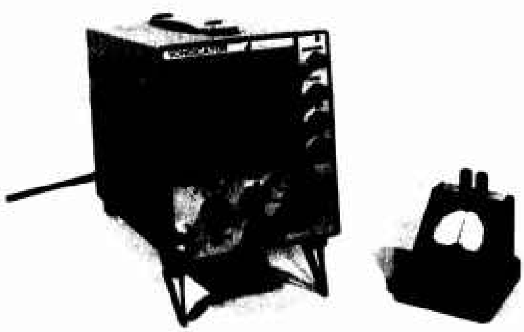


FIGURE 2
TYPE S-1 SONDICATOR WITH CRT AND METER READOUT

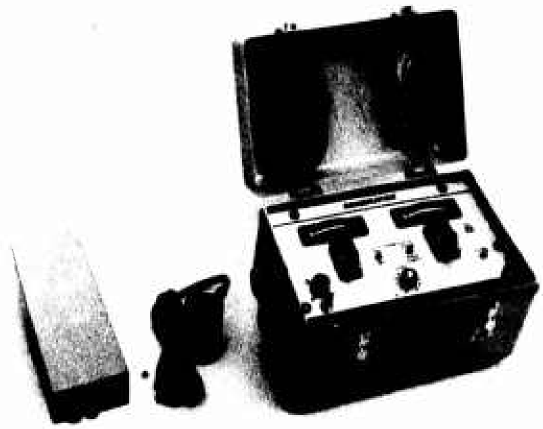


FIGURE 3
TYPE S-2B PORTABLE SONDICATOR – BATTERY OPERABLE

(LEFT) AIR COLUMN COUPLING
(RIGHT) DRY CONTACT COUPLING

FIGURE 4
SONDICATOR SEARCH UNITS

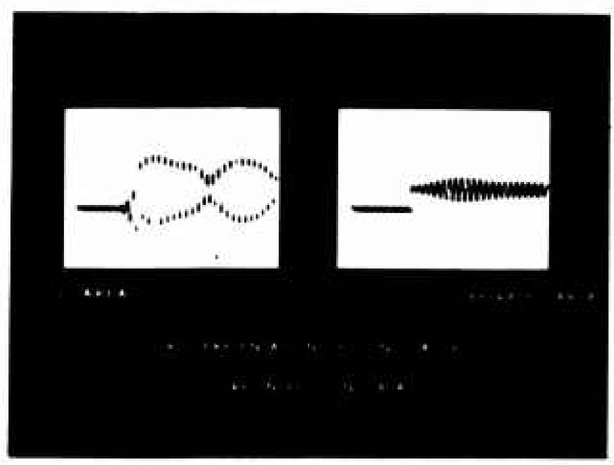


FIGURE 5
OSCILLOGRAM DISPLAY – TYPE S-1 SONDICATOR – SIGNAL DECREASE DUE TO FLAW

Tire inspection is done by positioning one search unit, usually the transmitter, inside the tire body, and one or more units for receivers outside (Figure 7). To maintain alignment, a C-clamp type fixture has been used (Figure 8). An early experimental system (Figure 9) comprised: (1) a simple tire rotate fixture, (2) dual search unit holder, (3) Type S-1 SONDICATOR with analog output, and (4) chart recorder.

It must be emphasized that the principal effort within our Company up to this time has been directed toward the inspection of used aircraft tires. There are several reasons including the following:

1. The need for high reliability and the relatively large value per tire justify the test cost.

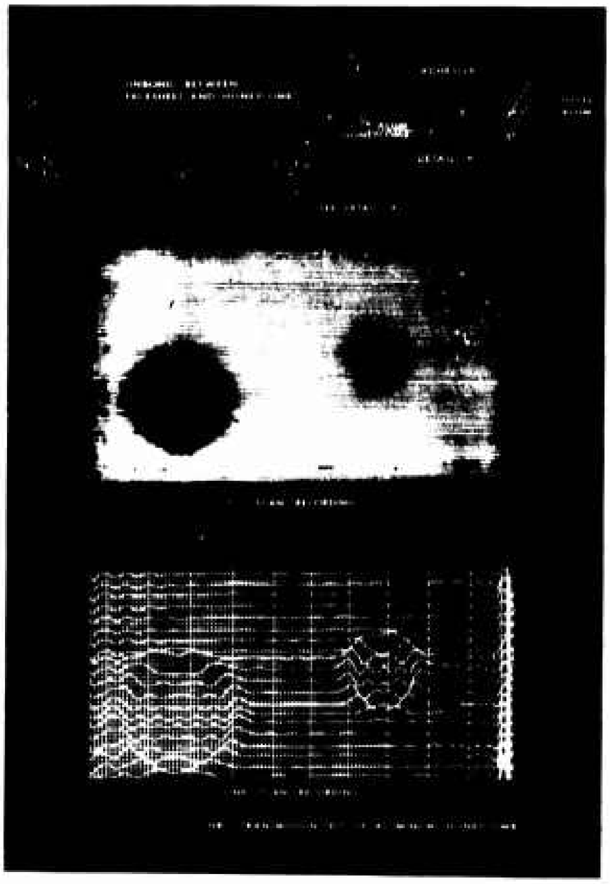
2. The usual tread pattern of aircraft tires consists of simple circumferential grooves which produce no irregularity in the transmission pattern during rotational scanning.

3. Both the military and civilian carriers have indicated interest in improved NDT methods, especially for retread operations.

Using the single channel system of Figure 9, the entire tread area can be inspected by scanning 360 deg and then moving the search unit fixture laterally to examine the next circumferential increment. At the same time, the recorder stylus is moved to produce another line trace. A typical recording for a buffed tire with no known defects (Figure 10) shows relatively smooth tracings – each eight divisions represents one 360 deg scan for the seven passes taken. Indexing depends on the search unit diameter and incremental sensitivity desired. With standard 1-in. diameter SONDICATOR search units, artificial laminar flaws as small as 1/2 in. were consistently detected. A multi-pass chart for a tire containing a large number of such reference discontinuities is shown (Figure 11). While the single-channel system is suitable for experimental studies, it is not adequate for inspection of large quantities in any reasonable time. Therefore, multichannel instrumentation was considered to decrease test time per tire.

Our Australian colleagues at Automation Sperry Pty., Ltd, have been especially successful in developing and applying sonic tire testing commercially.

Their instrumentation (Figure 12) provides six or more channels, each separately adjustable for sensitivity, gate position, and alarm. The rotate fixture (Figure 13) employs vertical tire positioning at a small angle for stability. The transmitter search units are mounted inside the body, and the multiple receiver head outside near the top (Figure 14).



(CENTER) C-SCAN INTENSITY FLAT
(LOWER) ANALOG MULTIPLE LINE SCAN

FIGURE 6
READOUT OF X-Y SCAN OF HONEYCOMB SAMPLE

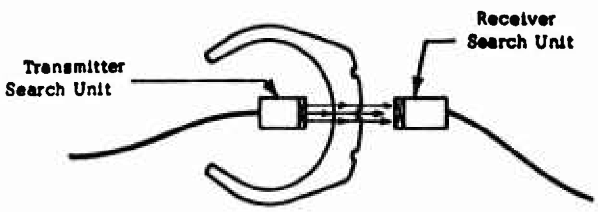


FIGURE 7
PRINCIPLE OF THROUGH-TRANSMISSION TIRE TEST

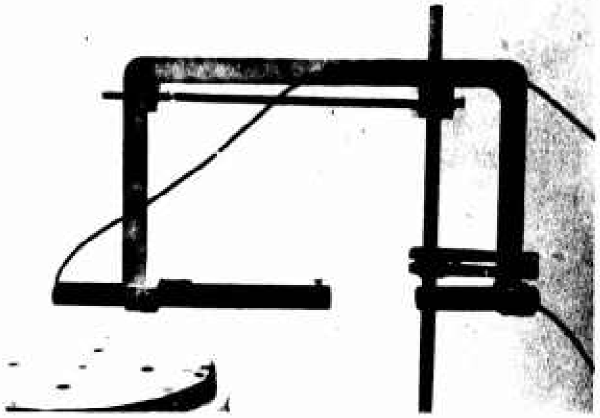


FIGURE 8
C-CLAMP SEARCH UNIT HOLDER

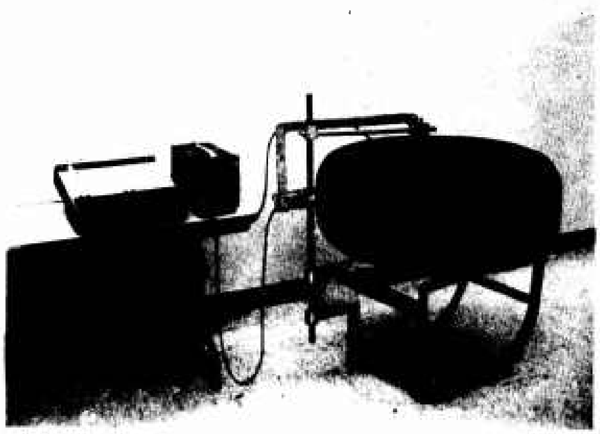


FIGURE 9
TIRE TEST FIXTURE WITH TYPE S-1 SONDICATOR
AND HORIZONTAL ROTATOR

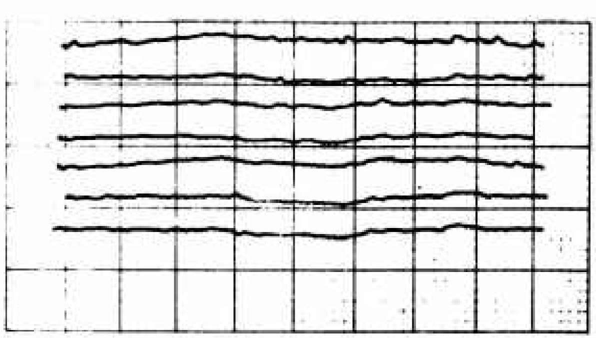


FIGURE 10
MULTIPLE LINE CHART –
6 PASSES BUFFED AIRCRAFT TIRE

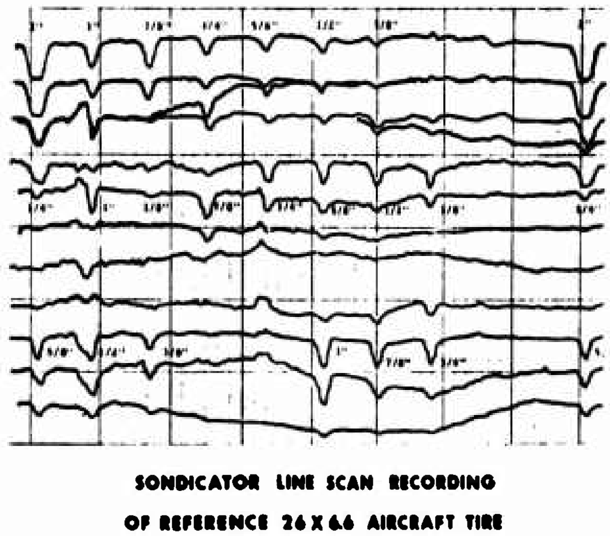


FIGURE 11
LINE SCANS – 12 PASSES REFERENCE TIRE
WITH ARTIFICIAL DEFECTS

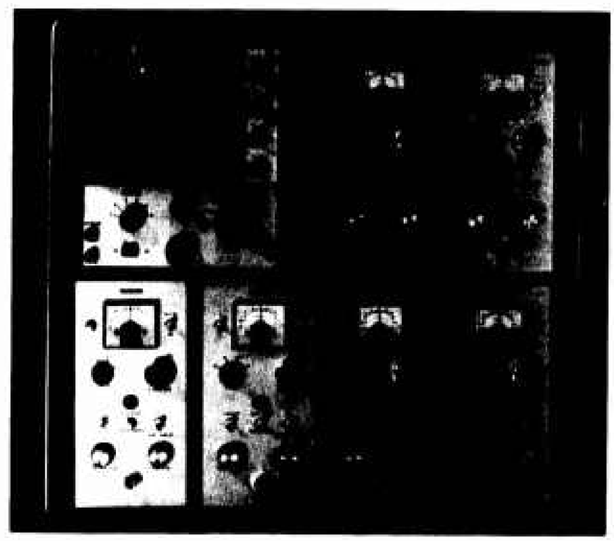


FIGURE 12
INSTRUMENTATION – ASPTY 6 CHANNEL SYSTEM

The mounting allows the search units to adjust to the tire contour, to hold the distance constant, and to follow the tread groove pattern without wandering. This is most important since tread discontinuities produce variations in single phase as well as in the standing wave patterns, thereby giving false indications of amplitude change. This system has been in use in Australia for about two years, and, as of April 1973, several hundred retread tires for commercial airlines have been inspected. The entire tread of a DC-9 or 727 main wheel can be done in two passes. Defects are considered to be those discontinuities which produce at least 90 percent loss of transmitted signal. These trigger the alarm circuits, and the angular position is then marked on the tire as well as in the record sheet. At the time of last reports, rejectable tires were running about 1½ percent.

Retreading is being done up to six or seven times based on service experience and the availability of the sonic test. Both Trans-Australia and Ansett Airlines are utilizing the test service which is presently offered at a cost of about $6.00 per tire. Inspection of sidewalls is also being investigated. Similar equipment has been installed in the Rotterdam facilities of Automation Industries, Inc., to serve the European area. In the United States, the Type S-6 SONDICATOR originally developed for plywood testing has been applied to several tire programs. This is of modular design accepting up to six receiver and alarm channels with separate relay outputs and selectable signal viewing on a panel CRT display (Figure 15). Twelve channel systems can also be provided where desirable. A later version of the Boulder Research experimental tire system using the S-6 SONDICATOR is shown (Figure 16). One major retreader serving the military has effectively adapted this instrumentation to a semi-automatic inspection station of his own design. An array of receiver search units is guided along the tread surface, and one or more transmitters mounted inside the tire body to give full tread coverage.

In summary, the advantages of air-coupled through-transmission testing of aircraft tires are: (1) convenience, (2) speed, (3) ease of interpretation, (4) elimination of wet couplants, especially on inner surface, and (5) good sensitivity to laminar defects. Limitations include: (1) no depth information, (2) requirement of good mechanical fixturing, (3) moderately elaborate electronics and search unit assemblies, and (4) somewhat susceptible to external environmental noise.

Major contributions to the programs described have been made by Automation Industries Research group, formerly at Boulder, and by our associates in Australia and Holland. The support of the Air Force is also gratefully acknowledged.

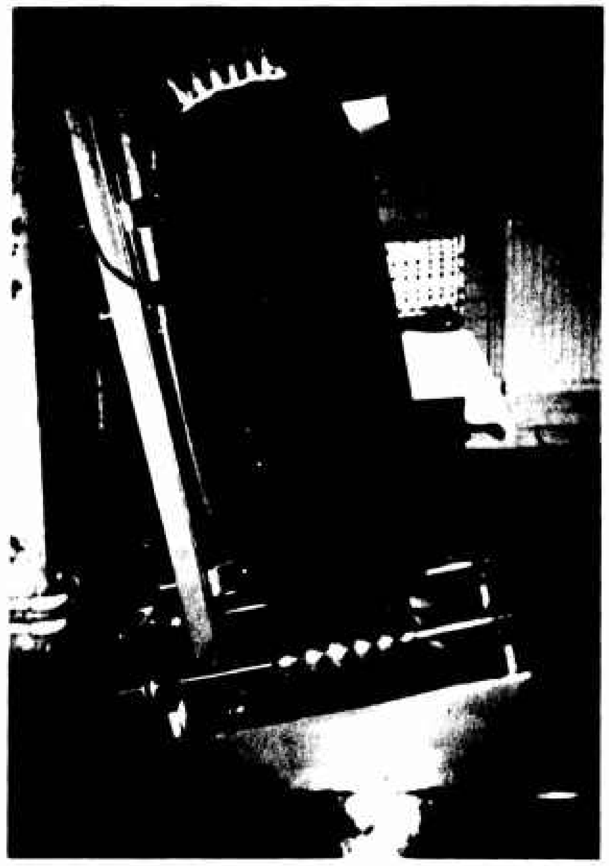


FIGURE 13
ROTATE FIXTURE AND SEARCH UNITS – ASPTY SYSTEM

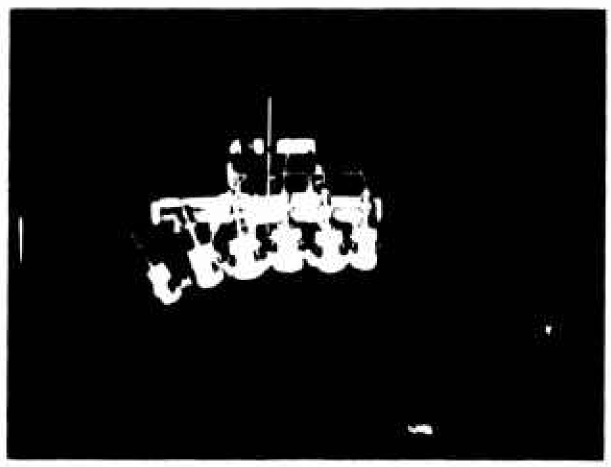


FIGURE 14
SEARCH UNIT ASSEMBLY – ASPTY SYSTEM

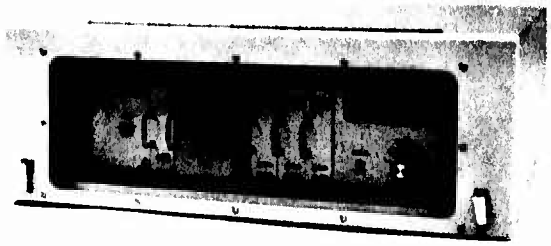


FIGURE 15
TYPE S-6 SONDICATOR WITH 3 MODULES

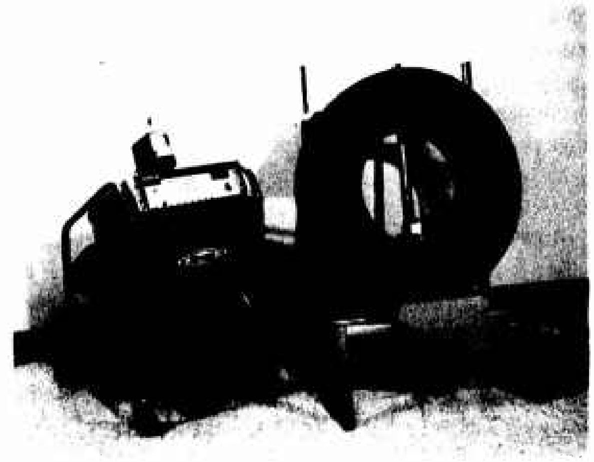


FIGURE 16
ROTATE FIXTURE AND 6 CHANNEL SONDICATOR

QUESTIONS AND ANSWERS

Q: What is the smallest size tire you can inspect with the system?
A: Mr. Van Valkenburg: I don't really know how to answer that. Size is no problem, except for fixturing the transmitter on the inside, and in a tire with very narrow bead width this could be nasty. At the present time, we haven't worked with anything much smaller than the equivalent of a 14-in. passenger tire.
Q: What type of transducers are you using and what is the life expectancy of them?
A: Piezoelectric ceramic elements are used. The life expectancy should be long, but sometimes, due to conditions beyond our control, they don't last. At the present time, we're using two types of transducers. One has a screen face and lasts almost indefinitely, unless it's crushed. These are called "receivers" and are usually mounted above the sample so that the particles don't fall in. The other type of transducer has a facing glued on it, and these may fail due to the deterioration of the glue, mechanical shocking of the case, or crushing it when mounting. We're not sure that any have failed just due to mechanical vibration of the piezoelectric elements.
Q: Several times today we've heard people indicate that one of the problems is deciding how significant the anomaly is. Now, apparently, in the aircraft retreading business you, or somebody, has decided what size you will reject – is that correct? If you have decided that, would you be willing to tell me what it is.
A: Specifications have been arrived at, primarily by determining the signal changes due to known artificial flaws. On this basis, laminar areas 1/2 in. square or larger are considered detectable when aligned with the sonic beam. Conversely, typical production tires produce substantially smaller indications. Automation Sperry Pty., in cooperation with the domestic Australian airlines, have established a test procedure and acceptance specification which sets categories of essentially three levels. Disposition of each is determined by the airline. The amplitude change plus the extent of the indication are considered. On the basis of rejecting any evidence of severe laminations, we are told that in-service failures due to these defects have been eliminated.
Q: How high did you go up in frequency, and what is the limiting factor for the frequency return?
A: For the air-coupled through-transmission system, we already are at the point where we need more gain or more power to go up in frequency beyond about 22 kHz. Obviously, you could achieve either at a sacrifice of cost and efficiency. More receiver gain results in a monumental problem from ambient noise. The transducers, even with filtering, are relatively sensitive to ambient noise.
Q: What sort of power input do you use for a transducer?
A: We never measured the power. The pulse is a few hundred volts, and the effective impedance is probably several thousand ohms giving a peak power of a few watts. Ordinarily, in pulse systems power isn't a concern, because there is no heating problem. The pulse wave-train is usually about 5 cycles, so a 22 kHz pulse at 10 pulses per second gives a very short duty cycle.
Q: How long does it take to test a 40x14 size tire?
A: With a six-channel system the test could be done in about 3 min by taking two complete revolutions and switching search units to achieve twelve passes.

NONDESTRUCTIVE INSPECTION OF AIRCRAFT TIRES BY USE OF PULSE-ECHO ULTRASONICS

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ABSTRACT

It is currently mandated that rebuilt high speed/high performance aircraft tires for NAVAIR be 100 percent shoulder-to-shoulder nondestructively inspected by the rebuilding contractor. A suitable system for in situ *inspection of tires on the flight line is required. The Naval Air Development Center is currently optimizing a prototype pulse-echo ultrasonic system to accomplish these requirements.*

Due to recent technological advances in ultrasonic flaw detecting apparatus, it is shown that this inspection is now possible. The critical acoustic properties of rubber and rubber composites have been studied so that optimum system requirements may be determined. Using off-the-shelf components, an inspection apparatus has been constructed to demonstrate the ability of pulse-echo ultrasonics to locate critical internal flaws and structural elements.

BACKGROUND

New tires currently comprise one of the more costly logistic support items for Naval aircraft. However, suitable used tires can be retreaded at one-fourth the average cost of the original new tire [1]. Consequently, 90 different types of tires are being retreaded by several qualified tire rebuilding companies [2]. Since each of these companies has more than one plant location, there results a considerable range of rebuilding quality among and between the various facilities. Therefore, the inclusion of one or more nondestructive inspections during the rebuilding operations would provide uniform quality while also providing a means of gauging the ability of a rebuilt tire to withstand additional life cycles [3].

The addition of nondestructive inspection techniques to new tire procurement, to maintenance inspection, and to the current dynamic qualification and destructive test programs will yield considerable additional safety and savings. Automated nondestructive tire inspection systems must be developed which will enable acceptance inspection of each new and rebuilt tire and inspection during routine in-service maintenance if maximum reliability and efficiency are to be achieved.

There are several methods with proven applicability to nondestructive tire inspection [4]. Ultrasonic methods of inspection are outstanding from the viewpoints of inspection cost, inspection time, and fault resolution. The pulse-echo ultrasonic technique offers even more advantage due to its characteristic high sensitivity to internal composition and flaw depth perception. These characteristics allow the location of internal inhomogeneities in all three space dimensions, thus enabling complete mapping of the placement of structural elements comprising the tire. Further, since the pulse-echo technique requires access only to the tire exterior, it also has the potential of flight-line tire inspection. This is a critical application which no other established method has proved able to accomplish. While the methods of radiographic, infrared, and holographic inspection may be accomplished with access to the tire exterior alone, these methods have not shown practicality in the maintenance application despite a considerable development effort.

In the past, the pulse-echo ultrasonic technique has been studied as a possible nondestructive tire inspection method with little success [5-7]. It is now obvious that such conclusions were based upon improper system parameters and limitations in ultrasonic technology. Recent improvements in the technology have significantly improved the attractiveness of the pulse-echo ultrasonic technique for tire inspection [4, 8-13].

Related to the problem of providing an inspection system is the determination of the relation between actual tire failure phenomena and internal flaws. Little effort has been expended on this most important task to date. However, active testing programs have been initiated [14].

Concurrent with the study of flaw detection and evaluation based upon failure data is the necessity for known flaw standards in both new and rebuilt tires. The present effort

includes procurement of aircraft tire defect samples necessary to quantitatively evaluate an inspection system capability. In turn, nondestructive test procedures have been of value in development of the optimum processes utilized for the fabrication of these defect standards.

FUNDAMENTAL PROPERTIES OF AIRCRAFT TIRES

Ultrasonic pulse-echo methods hold such rewards for tire inspection that it is important to review the technique in light of recent advances in the state-of-the-art of ultrasonic technology. The first step toward development of a tire inspection system based upon ultrasonics was a study of the materials and specific structures of aircraft tires in relation to the propagation of ultrasound.

Several methods of tire construction exist which result in tires of widely differing acoustic characteristics. Figure 1 shows a typical tire cross section. Variations are due to the presence or absence of the tread reinforcement, number, density, and material of the carcass plies, liner material, exact rubber compounding mixtures, and the overall physical dimensions for different sizes and styles of aircraft tires.

As an ultrasonic wave progresses at the speed of sound into the tire, energy is reflected by inhomogeneities [5]. This principle is the foundation of the pulse-echo ultrasonic inspection and allows an examination of internal features through detection and analysis of reflected acoustic energy. It is well known that the pulse-echo method has a greatly enhanced sensitivity to changes in internal properties as compared to the through-transmission ultrasonic technique

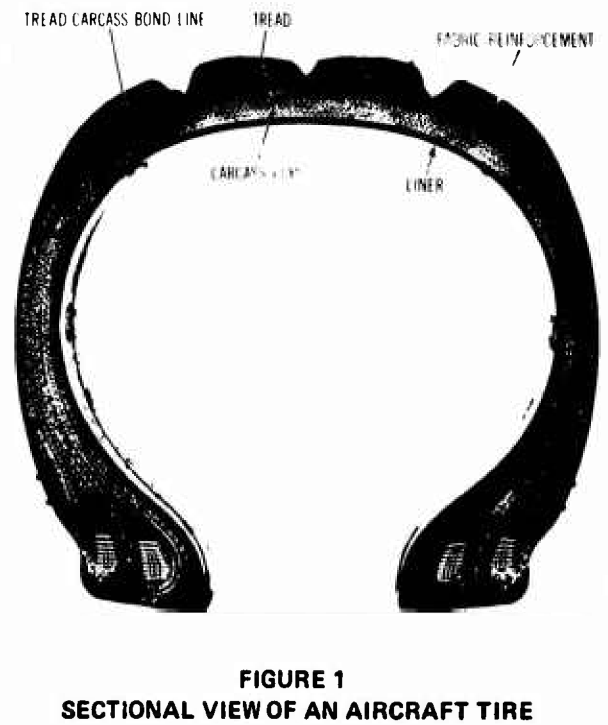


FIGURE 1
SECTIONAL VIEW OF AN AIRCRAFT TIRE

(which examines the ultrasonic energy able to penetrate the test object completely) when the reflected energy is a small percentage of the overall acoustic energy.

The previously mentioned variations in tire construction cause the results of ultrasonic inspection to vary with the tire style. There are certain common properties, however, and among these are the acoustic properties of rubber itself. The most significant obstacle to ultrasonic inspection is associated with the large attenuation exhibited by rubber. While a reduction in the frequency of the sound does allow more acoustic energy to penetrate rubber and rubber composites, the corresponding increase in wavelength, or physical extent of the disturbance, results in a loss of spatial resolution. For example, at 1 MHz in rubber, the wavelength is approximately 1.5 mm, while at 100 kHz it becomes 15 mm. Since typical carcass cord spacing is on the order of a millimeter, the longer wavelength does not permit resolution of individual carcass layers [4]. The fact that the carcass and reinforcement cord have very low densities and do not support ultrasonic waves makes these elements excellent reflectors. Pulse-echo ultrasonics can, therefore, easily detect and prove these tire elements.

Water and rubber have nearly the same ultrasonic velocity and density and hence very close acoustic impedances. Coupling ultrasonic energy from a water-to-rubber medium is, therefore, relatively efficient. For example, for an ideal, or plane and smooth, water-rubber interface the coefficient of reflection for plane waves is approximately 1.8×10^{-3}, which means that 99.9 percent of the energy will enter the rubber from the water. Water coupling to the tread surface should be ideal for automated tire inspection. Addition of glycols or other select chemical agents, which are harmless to rubber, to the water couplant will improve the acoustic match and further reduce the reflected energy arising from this interface. Minimized reflected energy from this source is necessary in order to inspect tires in the region where tread design could otherwise produce extraneous results. Also, reduction of this echo in combination with sufficient water path will help eliminate spurious signals interfering with detection of small echoes. Direct contact inspection is possible although more difficult due to surface irregularities, variable transducer-surface reaction, nearfield loading of the transducer, and transducer noise.

In order to obtain satisfactory spatial resolution, it is necessary to generate short pulses of ultrasound. The spatial extent of the ultrasonic disturbance is approximately cn/f_0, where c is the sound velocity, f_0 the predominant frequency, and n the number of cycles excited. Frequency content of short radio-frequency bursts of ultrasonic energy is illustrated by Figure 2. Typical pulses, with a center frequency of $f_0 = 1$ MHz and pulse length of $T_0 = 1.5 \times 10^{-6}$ sec, introduced into natural vulcanized rubber

allow a resolution of only those defects more than 2 mm apart in the direction of propagation. This assumes that further resolution degradation, due to dispersion, for example, is negligible. The generation of such pulses requires a broadband ultrasonic transducer. Advances in the state-of-the-art of the transducer fabrication and materials have made possible broadband transmitting and receiving elements with excellent conversion efficiencies. Further advantages in the use of broadband ultrasonic transducers, with regard to desirable radiation field patterns, have been discussed in current literature [16].

Connected with the large frequency-dependent attenuation of rubber is the fact that nonsinusoidal signals suffer changes in wave shape or dispersion during propagation. In effect, the material functions as a low pass filter to the broadband ultrasonic pulse. Dispersion increases with the length of the propagation path in such material. The result is an apparent progressive reduction in the predominant frequency of the ultrasonic wave packet and physical spreading of the wave packet in space. As a consequence, spatial resolution is significantly reduced with increased depth into the tire. However, as defects deep within the carcass are presently considered less significant than similar defects closer to the tread [14], this limitation should not prove serious. Figure 3 demonstrates typical progressive dispersion of an ultrasonic pulse in rubber.

To overcome the loss of energy and dispersion during propagation, a broadband, high-gain detector is required. In the pulse-echo technique, the same transducer functions as both ultrasonic generator and sensor. The previously required broadband nature of this element as the transmitter also allows efficient operation as the receiver in the detection of the reflected dispersed waves. A broadband, low-noise, high-efficiency transducer is, therefore, critical to successful tire inspection.

Use of broadband, high-gain electronic amplification will allow detection, display, and processing of the reflected signals. Limitations of this approach are due only to the finite signal-to-noise ratio of the received information, assuming electronic noise is negligible. Increased signal levels over the electronic noise may be realized through increased transmitted ultrasonic energy and focused transducers. The use of broadband ultrasonic systems for penetration and resolution in materials exhibiting large attenuation and dispersion have been confirmed by others [17].

Figure 3 shows typical signal levels generated in an ultrasonic transducer. The ultrasonic wave depicted in these photographs was launched by the application of a 200-volt pulse to the transmitting/receiving transducer. The wave

$g(t) = A[U(t) - U(t-T_0)] \sin(2\pi f_0 t)$, where U is the unit step function.

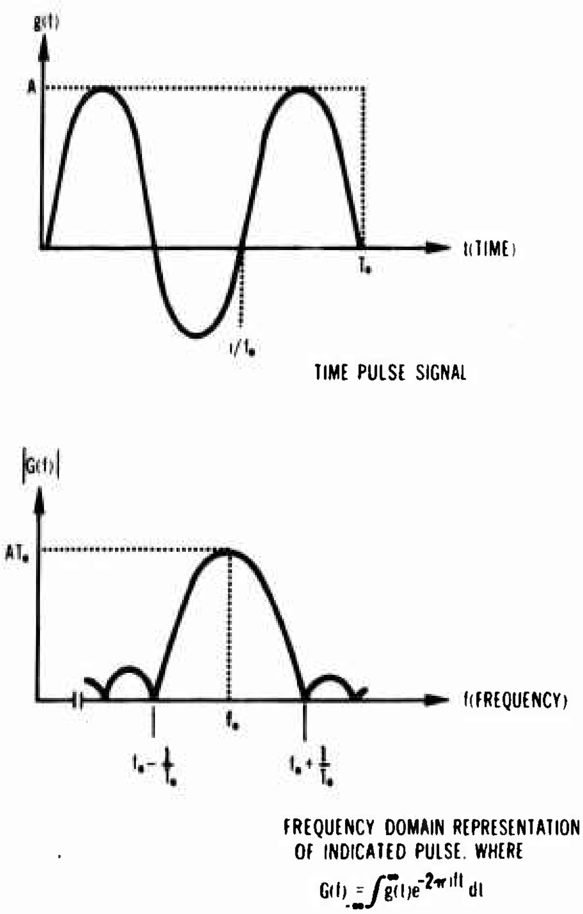
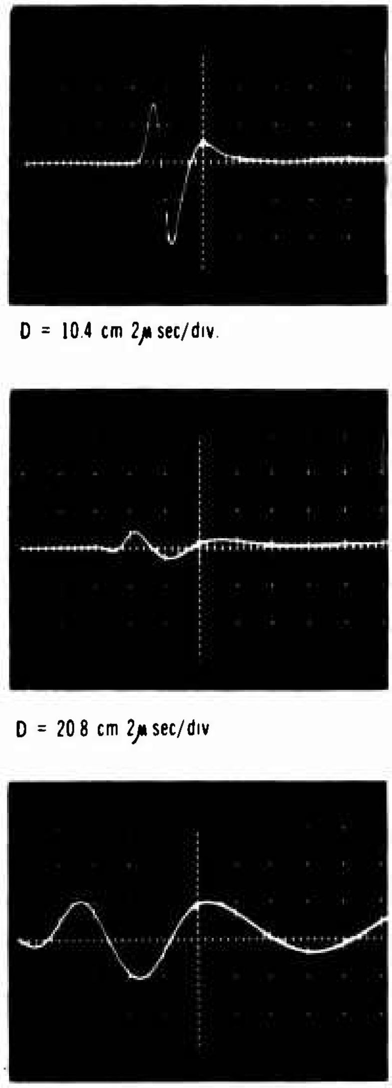


FIGURE 2
FREQUENCY SPECTRUM OF A SHORT DURATION SINUSOIDAL ULTRASONIC PULSE

subsequently traveled one-half the specified propagation distance in vulcanized, filled, natural rubber, suffered a total reflection from a plane-air interface, and returned through the remaining half-path-length distance to the transducer. These acoustic signals produce electric voltages on the order of tens of millivolts. Since attenuation for a round trip path in a typical tire* is approximately 100 db more than the loss involved in the path of Figure 3, signals on the order of a microvolt are to be expected from reflections at the tire liner-air interface. Detection of such feeble, distant echoes is more difficult. However, detection of echoes from flaws, not quite so distant from the tread, is certainly possible. In fact, while a clear, distinct echo from the rear tire surface in the tire described is not observable on standard inspection equipment†, there is positive indication

*Data is for a 17.00x20, type III, cut-resistant, 22-ply rated (18 actual plies) tire with metal-reinforced tread.

†Lehfeldt MPT-10 pulse-receiver, Panametrics VIP-I-IT transducer.



0.05 VOLTS/DIV

a D = 10.4 cm 2μ sec/div.

0.05 VOLTS/DIV

b D = 20.8 cm 2μ sec/div

0.01 VOLTS/DIV

c D = 41.6 cm 2μ sec/div

FIGURE 3
ACOUSTIC PULSE DISPERSION IN RUBBER
(received signal after propagating distance 'D' through natural, filled vulcanized rubber)

that the rear surface may be monitored. This positive indication was noted while changing the acoustic impedance of material in contact with the liner, whereby a definite but slight change in the received echo pattern was observable at the expected A-scan location. Such penetration ability has not previously been reported in the literature.

NEW TECHNIQUES FOR ULTRASONIC INSPECTION

There are additional phenomena which can add to the attractiveness of the ultrasonic pulse-echo method of tire inspection. Since the carcass resembles a regular, stratified medium, an interference effect will occur at the proper frequency. In the steady state this phenomena has been used to advantage in commercially available equipment, but it has not been exploited in pulsed systems nor for tire inspection. With the short spatial extent of pulsed waves, this phenomena will allow examination of a few adjacent plies simultaneously. A ply defect will tend to destroy the fundamental nature of the interference and hence become observable. For a ply spacing of "d" millimeters, a frequency of C/2d is required to observe this interference when C is the ultrasonic wave velocity in millimeters per second. Since typical ply spacing is on the order of d = 1 mm, a center frequency of f_0 = 750 kHz is required. Broadband signals are desirable for the exploitation of this effect because they insure the presence of acoustic energy at the necessary frequency even when ply spacing is varying within a particular tire and from tire to tire. In competition with the interference effect is the large attenuation.

For very low coefficients of reflection R, or when the reflected energy is a small fraction of the total incident energy as is the case for small composition changes in rubber, the amplitude of the reflected wave is highly sensitive to local changes in material properties, as exhibited in Figure 4. The reflected wave is also highly dependent upon the specific geometry of the interface. As present experimental results have suggested, it may be feasible to monitor one of the more predominant internal interfaces, such as the reinforcement layer or tread bond-line, to assess the integrity of the tire areas interior to these interfaces based upon these effects. A correlation of the variation in reflected energy originating from these easily distinguished interfaces with previous defect observations may allow significant simplification of the inspection evaluation as illustrated in Figure 5. This technique has not been previously suggested or applied to flaw detection in tires by others in the field.

A phenomenon which has been previously studied but not generally applied to the enhancement of flaw detection is the use of multiple-echo detection. It is easy to show that the reflected energy varies as R^{2n} for the nth internal reflection, where R is the wave amplitude reflection coefficient. Usually the first internal reflection where n = 1 is monitored so that the reflected amplitude signal varies in direct proportion to R. Slight variations in the specific acoustic impedance and the material properties of the interface causing reflection will, therefore, be correspondingly magnified. Two effects hamper the use of multiple-echo analysis, but these do not eliminate its effectiveness. First, attenuation arising from the additional propagation path length and additional reflections acts to reduce the signal levels of multiple echoes. Secondly, complication of the pulse-echo display results from multiple phenomena as described by Mundry [8].

For example, in a typical rubber composite and at an internal interface which is characterized by a reflection coefficient of $R = 10^{-2}$ or 1 percent reflected energy, a change in interfacial properties might result in a reflected signal variation of 2.5 db. Examination of the second echo will produce a corresponding variation of 5 db, and the third echo variation should be 7.5 db. Signal loss from the additional reflections is about 40 db per echo plus an additive factor of 17.5 ADn where A is the material attenuation number, D is the interface depth in the material, and n is the number of the reflection. For a tire bond line* the second and third echoes would be approximately 50 db and 100 db, respectively, below the primary echo level. Such predictions have been qualitatively confirmed experimentally.

INSPECTION SYSTEM DESCRIPTION

The previous brief review of interaction properties for ultrasonic waves and rubber composites determines certain requirements for an ultrasonic pulse-echo tire inspection system. Necessary criteria are low-noise, high-efficiency, broadband transducers; low-noise, high-gain, broadband electronic processing; and water coupling. For semi-automated inspection it is desirable to have electronically gated monitors and a defect recording and mapping system. Gating systems are standard accessories, and both C-scan and compound A-scan displays may be useful for defect analysis.

Under the present development program [19], standard equipment is to be integrated into a tire inspection system. The inspection system is schematically diagrammed in Figure 6. After considerable evaluation of modern ultrasonic transducers, it was concluded that the broadband series of sensors made by Panametrics, the VIP-1-1I, best fulfilled these requirements. A center operating frequency of approximately 1 MHz was selected. Several ultrasonic pulse-receivers would probably have sufficed; however, delays in availability of instruments for evaluation narrowed selection to the Lehfeldt MPT-10/MESWAIRT/SWAIRT with two flaw gates and an analogue echo amplitude feature of special data enhancing circuits including noise suppression. Photographic A-scan and echo amplitude recording is presently in operation with this instrument. An automatic C-scan system utilizing a facsimile drum recorder is under construction.

A mechanical subsystem for holding and rotating the tire consists of a standard tire handling machine, Branick GA/ER/EF/S. This was modified to allow a slower and adjustable scan speed on the tire under test. The current rate is approximately 2 rpm minimum. Positioning of the transducer search unit is accomplished manually with a modified microwave slotted-line carriage, search, tube, and miniature angle manipulator. The water immersion tank is a standard tire trough with the addition of a plexiglass window to allow observation of the transducer alignment.

Before the problem of tire fault detection may be properly investigated, tires with known standard defects must be procured. Since no standard procedures for the manufacture of known tire defects have been established, this area requires considerable effort. Presently, two rebuilt tires with built-in defects have been made available**. These tires have been examined by various inspection techniques including X-ray, infrared, holographic, and through-transmission ultrasonic methods, in round-robin tests to produce some knowledge of the true nature of the built-in defects. Soon to be completed are new tire defect standards. With such standards, the ability to detect and inspect for carcass separations and flaws will be more precise and quantitative in nature.

INSPECTION RESULTS

Defects as small as 1/2-in. diameter separations† at the tread-bond line in fabric tread reinforced tires are easily distinguished. Defects deeper in the carcass structure have been noted in laboratory tests; however, definite confirmation with the immersion system requires a standard defect tire of new construction††.

The new method developed at the NAVAIRDEVCEN of observing variations in near interfaces to investigate more interior structural defects has been substantiated by experimental results. In tread-reinforced construction the echo received from the reinforcement layer appears to be highly sensitive to internal properties of the tire. Figure 5 illustrates the magnitude of this effect and its ability to determine tire integrity.

---

*In a 17.000x20, type III, cut-resistant, 22-ply rated (18 plies actual) tire with metal-reinforced tread.

**These tires, which have been used at NAVAIRDEVCEN for evaluation of the present inspection systems, are:

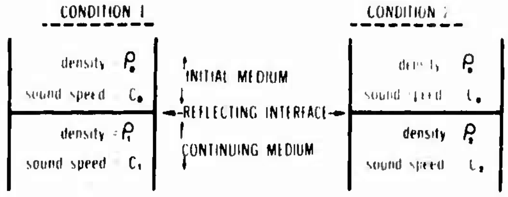
1. 26x6.6, 16-ply rating, SN 131451630E, retread defect tire standard made by Flight Treads of Atlanta, Atlanta, Georgia.
2. 26x6.6, 16-ply rating, SN 92750501, retread defect tire standard made by Air Treads of Atlanta, Atlanta, Georgia, for the U. S. Air Force, Hill AFB.

†This is the minimum size defect required to be detected for approval of tire inspection systems necessary for tire rebuilder qualification under Reference 3.

††Rebuilt tire with so-called defects below the tread-bond line contain in reality only bond line defects. The reason is that all deep defects require back filling to the rebuild bond line and hence produce inhomogeneities first appearing at bond line.

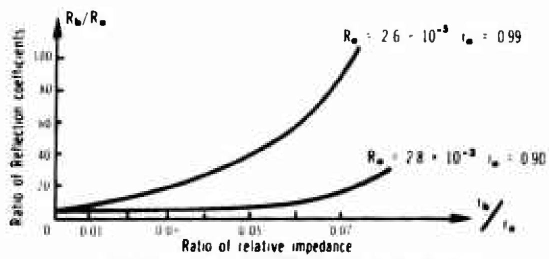
While other inspection techniques have been successful in detecting the defects shown in Figures 7 and 8 through round-robin tests, the pulse-echo method is the only one which indicates the depth of such defects in the tire and depth placement of internal elements. Depth information is extremely important because the severity of a flaw with respect to tire integrity is highly dependent upon its depth [14]. Also, other successful methods employed in these round-robin tests are not applicable to maintenance inspection *in situ*.

Fig 4a INTERFACE CONDITIONS CHANGE IS FROM CONDITION 1 TO CONDITION 2

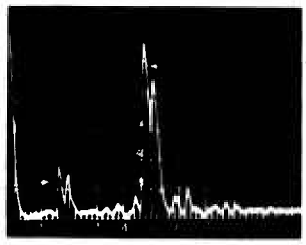


THE INTERFACE IS CHARACTERIZED BY THE RATIOS ... AND ... OF THE ACOUSTIC IMPEDANCES ...

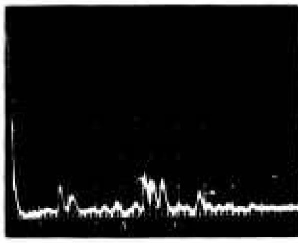
Fig 4b RELATIVE CHANGE IN REFLECTION COEFFICIENT Rb/Ra RESULTING FROM THE CHANGE IN INTERFACE PROPERTIES FROM CONDITION 1 TO 2



THE REFLECTION COEFFICIENTS R_a AND R_b ARE GIVEN BY



a NORMAL FILTERED PRESENTATION



b FABRIC REINFORCEMENT ECHO AMPLITUDE DECREASE ABOVE A 1 in DIAMETER SEPARATION
Instrument settings are identical to those of 5a

FIGURE 4
CHANGE IN REFLECTION COEFFICIENT WITH SMALL CHANGES IN REFLECTING INTERFACE PROPERTIES FOR PLANE WAVES

FIGURE 5
NADC ECHO AMPLITUDE MONITORING INSPECTION TECHNIQUE

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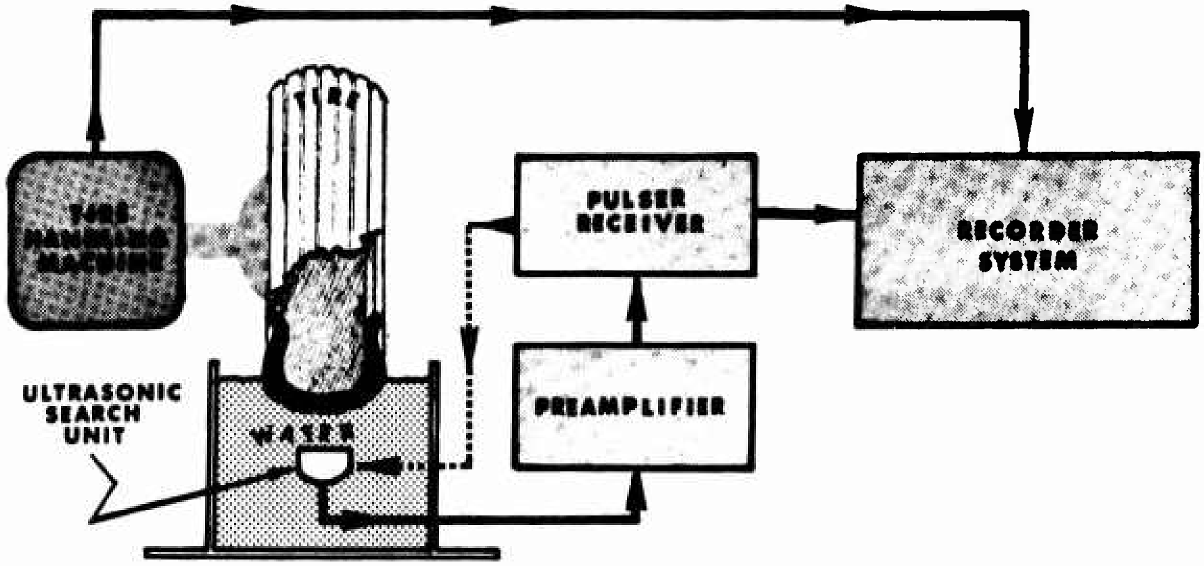

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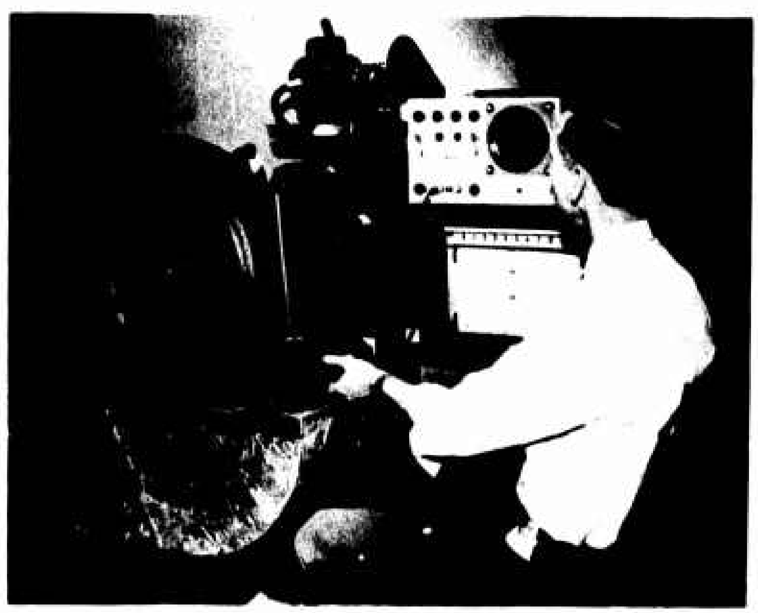

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FIGURE 6
ULTRASONIC PULSE-ECHO TIRE INSPECTION SYSTEM

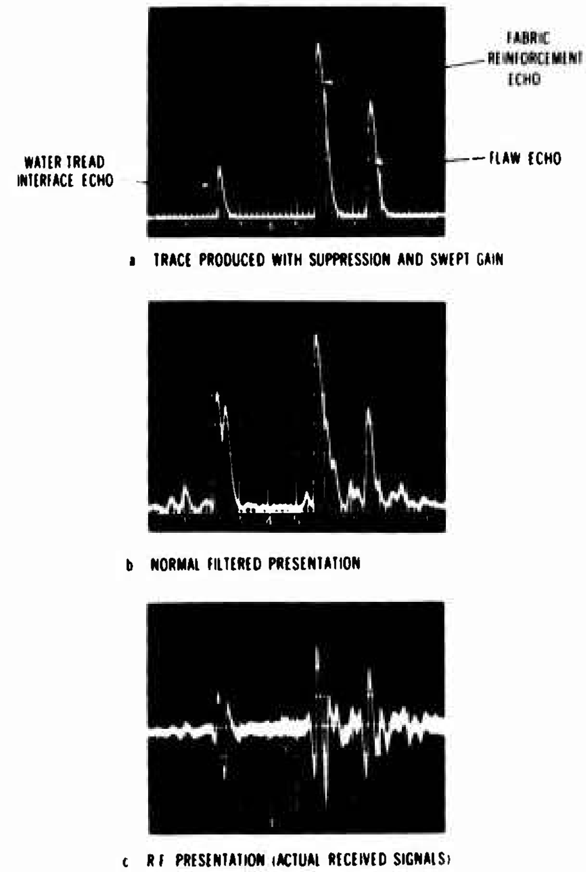

FIGURE 7
TIRE ECHO PHOTOGRAPHS INCLUDING
1 IN. DIAMETER SEPARATION

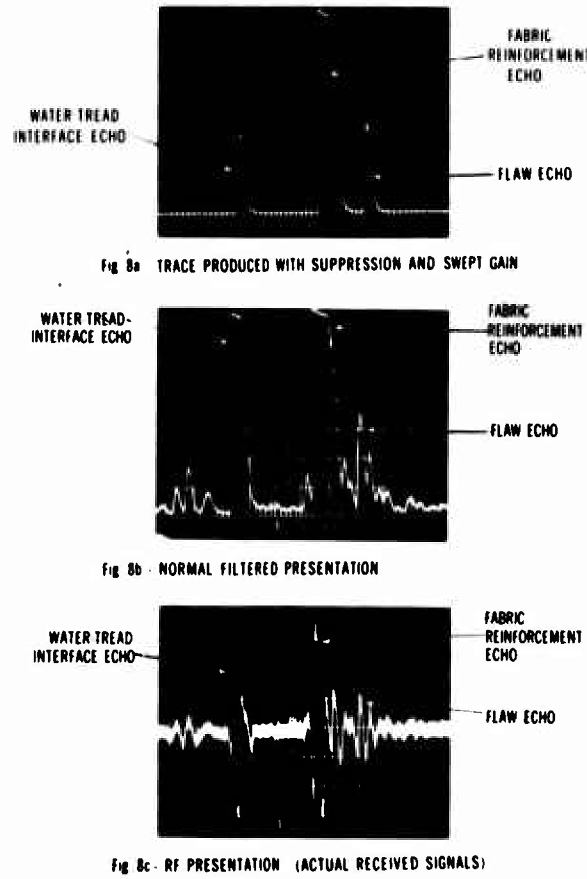

FIGURE 8
TIRE ECHO PHOTOGRAPHS INCLUDING
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CHAPTER V – INFRARED TIRE TESTING

INFRARED NONDESTRUCTIVE TESTING: TIRES AND OTHER APPLICATIONS

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ABSTRACT

Infrared nondestructive testing (IR NDT) is a passive technique employing infrared energy to obtain surface temperatures. Knowing many surface temperatures, an investigator can determine several physical properties associated with the quality of the test specimen. A variety of equipment exists today allowing for the most simple and manual to the most complex and automatic operations. Special systems include computer analysis and electronic image derotation (THERMOSTROBE) devices. Applications in the research and development of tires are associated with heat buildup under varying dynamic and static load conditions with new cords, rubber, belt configuration, flaws, ply separations, and other properties. Other applications of IR NDT are in the petrochemical, electrical utility, glass, steel, automotive, aerospace, and plastics industries. A motion picture illustrating the many applications of real-time thermal imaging will be shown.

INTRODUCTION

Infrared nondestructive testing is a passive and nonspecific technique usually employing infrared energy from the visible to 20 microns. The technique is both nonspecific in application and representation. In environmental studies the technique is called "remote sensing" and in medicine it is called "thermography." In each application area, the greatest difference occurs in how it is used rather than in the equipment itself.

As everyone knows, infrared energy is an invisible source. Therefore, whatever method is utilized to detect its levels or patterns which satisfy the needs of a particular requirement is the best method. This is true regardless of whether the visible format is in digits, graphs, color, black and white, or isometric patterns. Thus, the true "infrared picture" is the one which only obtains the necessary data – nothing more is more realistic or required.

Temperature is known to be a basic indication of the physical state of health of all objects. Although man has known this for a long time, it is only recently that it has been used quantitatively in quality testing. Even in medicine, the absolute reading and acceptance of a patient's temperature as an indication of his state of health was not widely established until the end of the last century

Widely developed, the measurement of infrared energy means many things to many very different people. To some it means an electrical hot spot detector, or a flaw detector, or a void detector or simply a remote temperature detector, or a pollution detector, personnel detector, cancer detector, fault detector, missile detector, inflammation detector, and so on. However, every user would like to think that the infrared system before him was invented specifically for his application and, better yet, only the week before. Nonetheless, new applications and equipment are continuously being developed.

Some people not only attribute diagnostic benefits to infrared instruments but, of course wrongly, prognostic benefits as well. Ask anyone in the medical thermographic business, and he will surely relate a tale of, when upon completion of a thermographic examination, the patient involved said: "What is this wonderful new instrument? I am beginning to feel better already!"

The preceding anecdote should not be taken too lightly. IR NDT by itself solves no problems. It is a testing procedure which often requires careful scientific thought and investigation. On first try its chief benefit may be to point to and establish real-world questions about the physical properties of the object. Once these questions are answered or in perspective, the correlation with the sought-after defects and faults may be found.

BASIC THEORIES (SIMPLIFIED)

There are two sets of theories related to the use of IR NDT devices. The first set explains the nature of thermal radiation; the second, the framework within which problems are solved. Both sets of theories are necessary for the efficient use of IR NDT devices.

Greatly simplifying the radiation theory, all objects naturally emit energy called thermal or infrared radiation. This energy is generally invisible but may be humanly "seen" or "felt" if it is intensive enough. When detected by instruments, this energy may be quantified in many different units as degrees or watts. From this, two important concepts emerge:

1. IR NDT devices are passive; they do not send out any energy in the manner of X-ray, radar or ultrasonic systems. Instead, they act as a thermal "sponge," absorbing and recording naturally emitted radiation.

2. IR NDT devices can "see" only energy emitted from an object's surface. If a thermomechanical action within an object effects a change in its surface temperature, this change could be detected; however, without special analysis, there will be no absolute indication of how deep beneath that surface the thermal action (or change in action) occurs.

In short, IR NDT devices neither see "into" objects nor generate infrared energy.

Two additional factors influencing the amount of energy actually emitted are spectral emissivity and angle of view. Both can be known and calibrated into the system.

Problems in NDT which require the use of infrared energy generally fall into two categories:

1. Type I problems involve remote surface temperature measurement where simply knowing the temperature of the object is the only requirement -- no other action is needed.

2. Type II problems go a step further. Here, knowing the temperature is not the end but only the beginning of a solution. It is possible that the temperature value itself is, in fact, irrelevant. Problems in NDT of tires often fall into this category. We are not so interested in the absolute temperature as we are in how certain radiant levels and patterns will indicate some particular quality (such as a ply separation) in the test speciman.

   For some applications the naturally emitted radiation is neither sufficient nor valuable for the data needed. In these cases, especially where internal information is needed, we may irradiate (e.g., with a heat gun) either the visible surface or the opposite surface so as to create an artificial heat pattern which can be correlated by means of its nonuniform conductance, to internal defects or other data.

An excellent example of the Type II category is the IR NDT of turbine blades. In this case, the desired information is wall thickness and the assurance of clear coring through the blade. Liquid Freon 12 under pressure is injected into the core of the blade while the surface is examined for degrees of cooling with time and then correlated to wall thickness – on the order of 263 mils.

In summary, all objects emit thermal energy, the amount of which can be measured and directly related to temperature. The temperature, either its natural or induced level, pattern, or rate of change is often an indicator of its physical state. Such features as thickness, voids, delaminations, cracks, density, separations, current level, and bonding may be correlated to surface temperatures. A theoretical analysis should be made to estimate the order of magnitude of the important variables in complex applications before equipment is considered.

EQUIPMENT

Remote spot temperature measurements with infrared techniques are usually quite straightforward. Employ the use of one of many kinds of IR detectors, add the necessary optics and electronics, and, finally, calibrate the device to read temperatures of a particular material. If there is one spot viewed at a time, the device is called a radiometer. There are many available of varying quality and configuration.

To obtain temperature information along a spatial x-axis, we use additional scanning optics and call this device a line scanner. If we wish to obtain x and y axis data, we use even more optics and call this device an imaging system. In both of the systems the temperature information is presented either as a vertically modulated line or an intensity or color modulated image. Although these infrared scanning systems are more complex, they offer far more data and are relatively simple to operate.

In considering equipment, it should be noted that infrared film is not sensitive to thermally emitted energy, and, as for scanning, there is not yet available an infrared vidicon comparable to television.

There are several IR NDT systems available today specifically developed for the tire industry. Here we must note that these systems are currently used most often in research and development rather than routine production NDT. Each of those discussed below is designed for rotating tires.

Thermopile and other detector radiometers offer low cost and simple operation and are probably the most widely used.

Several radiometers have been put together for tire testing systems. Such a system is offered by Sensors, Inc.

Line scanners, such as AGA THERMOPROFILE, are preferred by some manufacturers as an intermediate compromise. These systems read absolute values along a line of the tire and can be used whether the tire is rotating or not.

Imaging or x-y scanners offer not only the possibility to examine the entire surface temperature of a tire at once but also allow such examination while the tire is rotating. Monsanto's Tire Flaw Detector (TFD) utilizes a pair of detectors mounted on opposite sides of a mechanical scanning device providing the x-axis scan while the rotating tire provides the y-axis scan. Detector and sync signals are fed into a minicomputer allowing for detailed thermal cumulative and differential analysis of the surface temperature as well as automatic operation.

Several imaging systems are available which offer continuous visual display of the surface temperatures regardless of whether the tire is rotating or static. Such a system is AGA's THERMOSTROBE. Figures 1 through 5 illustrate this system which features color-coded temperature contours, isometric display, and line profiling, as well as providing video discs and computer interfacing when desirable.

The systems discussed above vary in cost from the lowest $100 detector to $50,000 with the most sophisticated data processing.

APPLICATIONS

Although there are many applications of IR NDT, and some of these will be shown in the following movie, it is appropriate here to discuss only tire testing. A list of other applications follows:

Generally IR testing falls into one of two categories:

1. Total temperature analysis of tires in research and development of new cords, configurations and other changes.

2. Defect and flaw detection of either production or prototype tires.

Falling into these categories are such applications as:

1. Detection of ply separations

2. Evaluation of tire carcasses before retreading

3. Studying the effects of different tread designs

4. Checking on cord centering in bias tires (balance)

5. Determining axial displacement of tread

6. Detecting poor rubber adhesion

7. Evaluating heat buildup related to various load and running time of different types of tires.

One tire cord manufacturer utilizes an infrared imaging system to screen defects inherent in a particular tire and not having to do with their newly designed cords

Other applications of IR NDT include:

- Refractory lining inspection of furnaces and reactors (steel and petrochemical industries)
- Electrical utility preventive maintenance
- Airborne remote sensing
- Quality control in glass, plastic, and electronic industries
- Research and development in automotive exhaust, heating and cooling systems
- Aerospace research and development of special materials
- Military systems
- Heat leakage in buildings
- Medical and veterinarian

SUMMARY

Infrared nondestructive testing is a new technique gaining wide acceptance in many applications. Radiation theory can be simplified to find absolute temperature values, and various methods can be employed to use infrared and heat conduction principles to obtain data on subsurface defects, voids, flaws, and other physical conditions. A number of IF NDT systems are available to the tire industry. Applications are many and varied with continuous development in almost every major industry.

FIGURE 1
FRONT VIEW OF THE THERMOSTROBE ADAPTER, SHOWING THE PHOTOELECTRIC PROBE AND CABLE

The tire on the right is stopped immediately after a test run, while the left one is a "strobed" picture at an equivalent running speed of 100 KM/H.

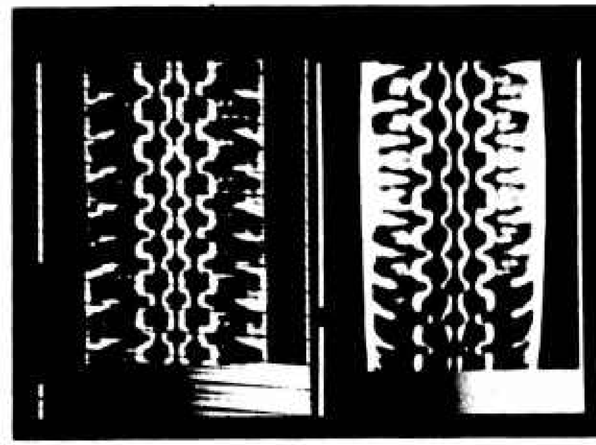

FIGURE 3
TWO THERMAL IMAGES OF THE SAME TIRE

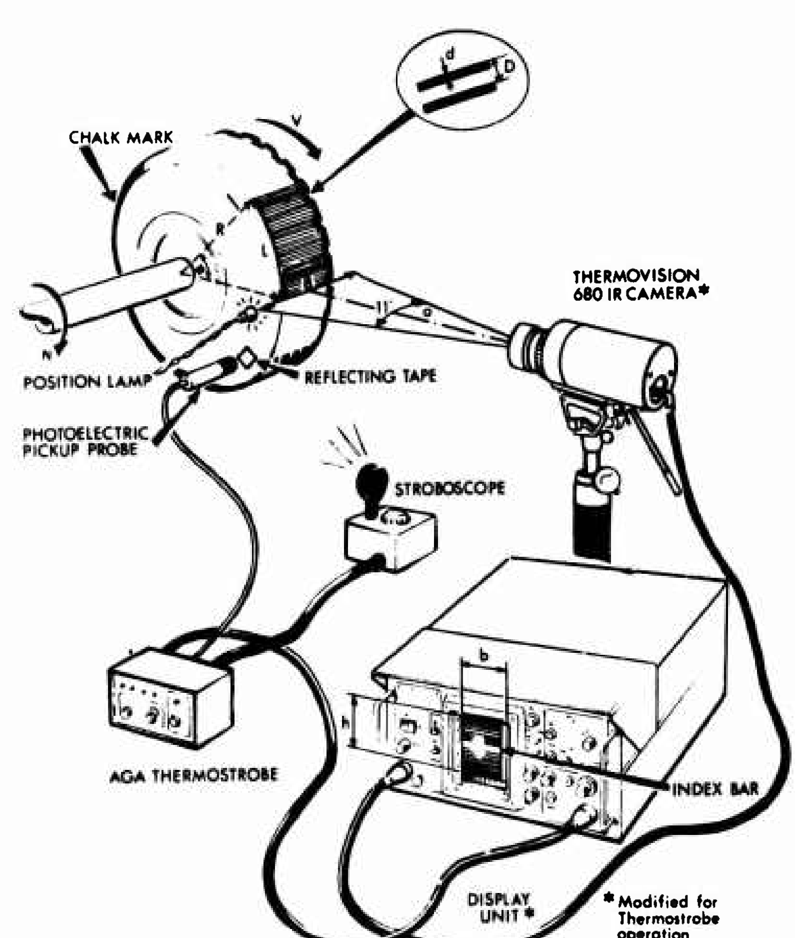

FIGURE 2
DIAGRAM OF THE THERMOVISION SYSTEM ADAPTER FOR STOPPED-MOTION VIEWING OF A TIRE UNDER DYNAMIC TEST CONDITIONS

FIGURE 4
ACTUAL SETUP AT A SWEDISH AUTOMOBILE INSPECTION STATION, WHERE THE THERMAL IMAGES OF RETREADED TIRES WERE INVESTIGATED

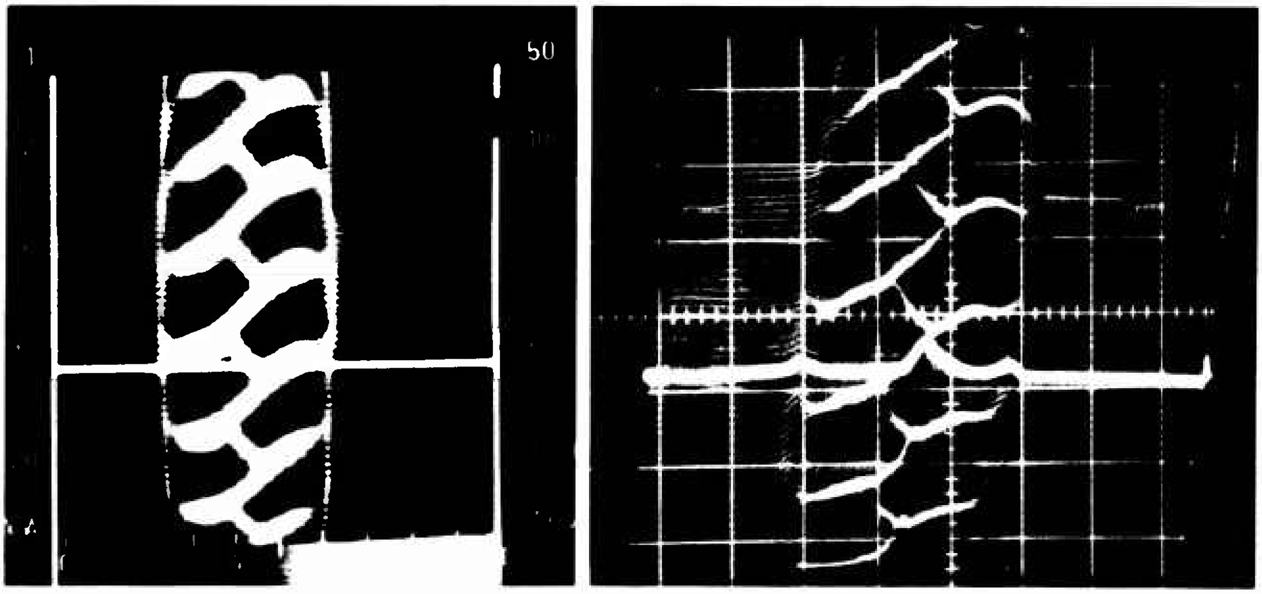

FIGURE 5
STOPPED-MOTION THERMAL IMAGE OF AN "EARTH-MOVER" TIRE RUNNING, WITH TEST-MARKER LINE SUPERIMPOSED, AND AN ISOMETRIC (3-DIMENSIONAL) PICTORIAL IMAGE SHOWN SEPARATELY ON ANOTHER DISPLAY OSCILLOSCOPE – WITH THE SELECTED SCAN-MASTER LINE SHOWN IN PROFILE

APPLICATION OF INFRARED TECHNIQUES TO NONDESTRUCTIVE TESTING OF TIRES

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Presented by
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ABSTRACT

Early IR NDT of vehicle tires began with the use of radiometers and continued with infrared microscopes having long-focus objectives. Today, real-time infrared comeras are used with a test setup that permits observation of the tread and both sidewalls of a tire under simulated load. A variety of defects and incipient failures have been detected. Although feasibility of IR NDT for detecting certain types of defects has been demonstrated, the total capabilities of this method have not yet been explored, and considerable research and development is required.

INTRODUCTION

Infrared nondestructive testing has been demonstrated to have a number of successful applications of interest to modern industry. These include determination of bond quality, detection of flaws and discontinuities in laminated structures, evaluation of material porosity, and detection of cracks and cross-sectional variations.

Although there are several methods of classifying IR NDT applications, one that appears generally very useful is the active or passive nature of the sample. An active sample is one that is characterized by its emission of heat in its normal mode of operation. Examples include an electric heating element with power applied, electronic circuits with voltage and signal applied, or an automobile tire rotating under load. The nondestructive testing of such samples is based upon the detection of hot or cold areas that develop as a result of structural defects as compared to those thermal gradients that are produced by a structure in acceptable condition.

In contrast, a passive sample does not normally emit heat or exhibit thermal gradients. It must be artificially heated to develop the atypical thermal gradients that must be detected to reveal nonuniformities or flaws in the structure of interest. Examples of passive samples are laminates or honeycombs, and molded materials that may contain voids. Passive testing techniques have also been applied to automobile tires.

In general, it is easier to detect abnormalities in active samples since a typical thermal pattern of acceptable units is often soon established. In passive structures a method of heating must be developed to best reveal the flaw of interest. Methods that are successful with one product may be quite inappropriate for use with another. Methods that have been employed include steady-state heating from the front, back, side, and interior of the sample, plus transient heating employing a variety of sources and pulsing or scanning techniques.

Instrumentation for IR NDT includes radiometers, infrared microscopes, and thermographs, along with the variety of special apparatus required for generating thermal gradients by active or passive techniques. Depending upon the application, these instruments measure temperature, either relative or absolute, although there are occasions where emissivity or spectral radiation characteristics are the factors of prime interest.

Radiometers and IR microscopes are usually employed for measuring the temperature of single points on an object. In tire testing, both radiometers and IR microscopes have been used with scanning arrangements to expand their capabilities. In these applications radiometers are generally limited to the examination of spots having a diameter of 1 mm or larger, whereas IR microscopes can examine target areas in the region of 10 microns in diameter up to 0.1 mm or larger.

Thermographs are instruments that scan the field of view of an infrared detector over the area of interest and produce a thermal image on a CRT, film, or magnetic recording tape. Thermal gradients on the surface of the test object are depicted in the image as varying shades of gray. Color thermographs have been developed, and these display increasing

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temperature in colors ranging from blue to red. Thermal images are capable of resolving very small physical and thermal details upon the surface of the object of interest.

The theory of temperature measurement by means of infrared, and the operating principles and performance characteristics of the mentioned instruments have been described elsewhere. The remainder of this paper will be devoted to a review of examples of IR NDT of tires.

SCOPE OF TIRE IR NDT

Pneumatic tires are generally similar in construction regardless of the type of vehicle for which they are intended. Testing is required for four fundamentally important purposes.

First, a reliable [illegible] is required to perform research and to test all phases in the design and development of new structures and materials. Second, a means is required to exercise quality control during manufacture. Third, it is necessary to evaluate a tire carcass before recapping, and some means must be found to eliminate carcasses that have incipient or actual flaws. Finally, with the passage of automotive safety legislation by a number of States, a means for estimating the safety of tires may be eventually required as part of an annual State motor vehicle inspection.

Infrared has something worthwhile to offer in each of these four categories. It has been demonstrated that infrared can reveal flaws and imperfections that can cause tire failure, and that it can expose the development of such flaws up to the time of destruction.

Infrared permits continuous real-time observation of tires under test. It exposes defects that are not revealed by X-ray and eliminates the radiation hazard always present with that technique. Infrared reveals flaws invisible to ultrasonic testing and eliminates the harmful exposure to the water that may be required as a coupling material in such tests.

Other advantages of infrared testing include modest initial equipment costs, easy operator training, and the need for very little manual labor in setting up the test.

EARLY TIRE IR NDT

One of the first IR NDT methods was devised in the early 60's before many of our present-day instrumentation refinements were available.

The apparatus is shown in Figure 1. In this arrangement a fixed-field radiometer looks at the rotating tire by reflection off a rotating mirror. The mirror is driven by the illustrated synchro system which can drive the mirror at the same angular velocity as the tire. Consequently, the stationary radiometer is enabled to examine a particular selected spot on the tire's moving surface.

The rotating mirror can be made to move at a speed slightly different than the tire by means of the synchro differential. Then, the point being examined will be slowly scanned over the surface of the rapidly rotating tire.

ARRANGEMENT USING INFRARED MICROSCOPE WITH "ACTIVE" TIRE

Improvements in the response speed of the infrared instrument made it possible to observe the tire without the need for the rotating mirror and its accompanying synchro drive system. The concept of such an arrangement is shown in Figure 2. This arrangement shows the tire on a test stand being observed by an infrared microscope with an objective

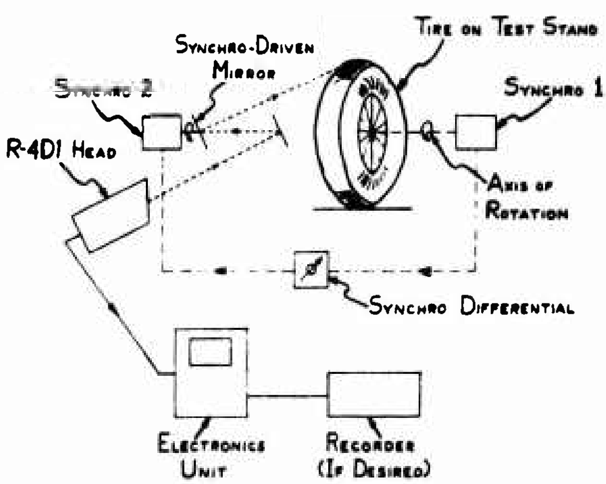

FIGURE 1
EARLY TIRE-TEST APPARATUS EMPLOYING FIXED-FIELD RADIOMETER AND ROTATING MIRROR

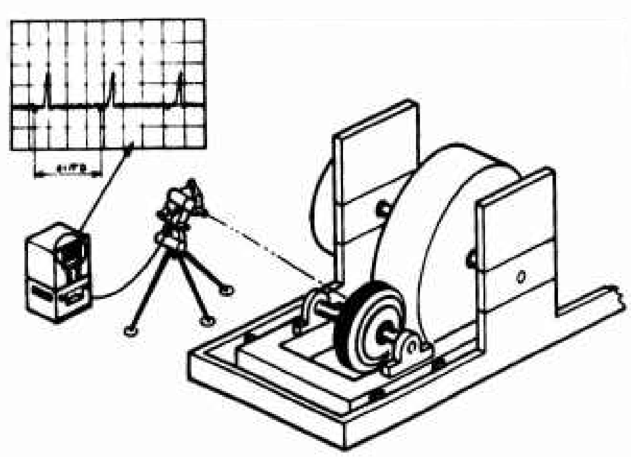

FIGURE 2
TIRE-TEST APPARATUS EMPLOYING INFRARED MICROSCOPE WITH OSCILLOSCOPE DISPLAY

lens having a long working distance. In this arrangement the instrument out ,ut is displayed on the oscilloscope screen, and a thermal profile around any desired portion of the tire can be displayed as a single sweep across the screen. If desired, a radial mark can be placed on the tire and used as a reference for precisely locating any thermal anomalies on the surface of the tire.

An arrangement such as this was employed at the Army Materials and Mechanics Research Center in Watertown, Mass., and is illustrated in Figure 3. In this setup the tire was tested in a dead-weight loaded dynamometer which permits the tire to be loaded by fixed weights to any degree desired while being rotated at a selected speed.

In this case the instrument was a Barnes Model RM-2A infrared microscope employing an indium antimonide detector cooled by liquid nit ogen and having a response speed in the order of 8 microsec. An adjustable stationary mirror was used to permit the microscope to view the tire while remaining in a vertical position, thus eliminating the need for any special arrangements to prevent spilling the liquid nitrogen. Subsequent microscopes of this model were equipped with a right-angle mirror attachment in the substage, to eliminate the need for the tripod-mounted mirror shown in the photo.

To make this measurement the instrument was equipped with its standard accessory objective having a magnification of 0.05X and a spot size of 0.38 in.

Thermal output was recorded on the strip chart shown on the stand in the background. The object above the recorder is the infrared microscope electronics control unit. Thermal output was also displayed on an oscilloscope. The oscilloscope sweep was triggered always at the same radius on the tire by means of a strip of aluminum tape on the back side of the tire. The electrical trigger was generated by a lead sulfide photo cell with a light source aimed so as to produce an electric pulse each time the aluminum tape crossed the light beam.

One test with this apparatus involved a new 8.55x14 passenger tire which was removed from the vehicle when a slight thumping was noticed during a prolonged high-speed run. The tire was of "premium" grade, tubeless and of bias-ply construction. Careful visual examination revealed a 1-in. diameter bubble in the tire shoulder, and the bubble was raised about 3/16 in.

In the tests the tire was mounted, balanced, inflated to a pressure of 15 lbs, and subjected to loads ranging from 35 to 50 psi. With these loads and pressure the tire tread was indented about 1/2 in., which caused a corresponding bulge in the shoulder. It was considered that, with this load and pressure, flexing during rotation would be sufficient to heat the tire in the region of the bubble, thus making it an "active" sample.

During the initial portion of the test, the tire was rotated at speeds ranging from 120 to 360 rpm. At the fastest speed each 0.38-in. resolution element on the tire shoulder was viewed for about 834 microsec. The instrument response speed of 8 microsec was much more than sufficient to respond thermally to each resolution element passing through the instrument field of view.

Best resolution of the defect was found when rotating the tire at 120 rpm with a load of about 50 psi. At this speed the thermal anomaly appeared as two spikes (see Figure 4) spaced so as to indicate a flaw slightly less than 2 in. in diameter. Subsequent sectioning of the tire (see Figure 5) indicated a separation measuring about 2 in. along the line of scan.

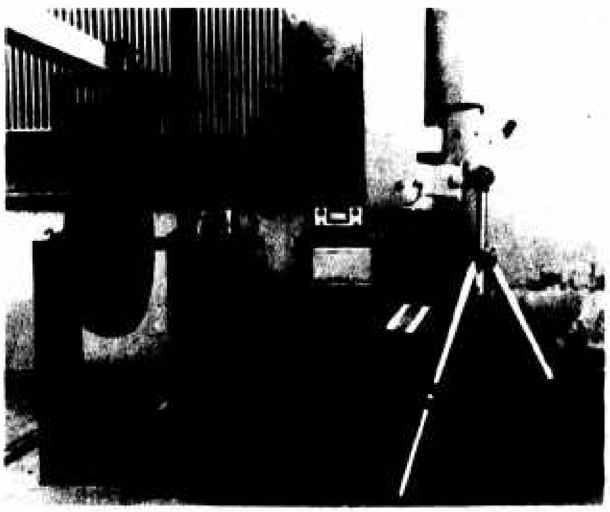

FIGURE 3
PHOTOGRAPH OF TIRE-TEST APPARATUS BASED UPON CONCEPT SHOWN IN FIGURE 2

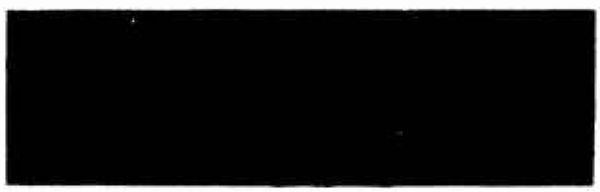

FIGURE 4
STRIP CHART RECORDING INDICATES TWO SPIKES SPACED TO INDICATE 2-IN. DIAMETER TIRE FLAW

ARRANGEMENT USING INFRARED MICROSCOPE WITH "PASSIVE" TIRE

Another phase of the investigation at AMMRC involved the use of the same microscope with the tire acting as a "passive" sample. The purpose was to test the feasibility of a test that eliminated the need for mounting the tire and the entire dynamic test setup. Such a test subjected the tire to no forces that might, in themselves, produce or accentuate any incipient defect.

The test setup is shown in Figure 6. The tire was placed on a turntable equipped with a motor suitable for driving it at variable speeds up to 3 rpm. A Henes hot air gun (not shown) was arranged to deliver a stream of air at 800°F through a nozzle 1/8-in. in aperture.

At a rotational speed of 1 rpm this produced on the tire a hot spot at 140°F which preceded by 6 in. the spot scanned by the microscope. This produced a time delay of about 5 sec on the shoulder or 4 sec at the tread between the time the spot was heated and the time that it passed under the microscope.

During this time the heat could diffuse through the tire structure and bring about thermal gradients capable of indicating a defect. For example, a separation between the plies would slow down heat diffusion and produce a warm spot in the surface above the separation.

During these tests the microscope was equipped with its objective having a 1X magnification, and a 0.02 spot size at a 9-in. working distance. Instrument output was displayed on a strip chart recorder.

One test involved a premium tire that developed a thump after being driven at 90 mph for 15 mi.

Figure 7 shows the recorder output for a scan along a rib almost in the center of the tread. A rather extended warm area indicates separation of the tread from the carcass for a circumferential distance of about 20 in. Also revealed is a small separation about 1 in. in diameter. Other scans indicated that the large tread separation extended well into the sidewall. Subsequent sectioning (see Figure 8) reveals the extent of the large separation. The smaller flaw was revealed to be 1 in. in diameter.

THERMOGRAPH TESTS

The development of a real-time thermograph made possible real-time examination of the tire under test. At AMMRC the tire was placed on a dynamometer and examined with a Barnes Model T-101 real-time infrared camera as shown in Figure 9. This instrument has a scanned field of 25 deg wide by 12.5 deg high at a rate of 4 frames per second. The instantaneous field of view is 0.1 deg, and the minimum detectable temperature difference is 0.2°C. The thermal image on the CRT contains 95 scan lines each with 225 separate resolution elements.

A number of tests were made in which the instrument viewed the tire tread and one sidewall. In one such test, before starting, the tire was at uniformly ambient temperature as shown in Figure 10. Within seconds after starting, the tread was heated beyond camera sensitivity and formed a bright arc in the image (see Figure 11) due to friction on the dynamometer. In about 2 min after starting (see Figure 12), an additional arc of lesser brightness formed in the region of the sidewall due to heating caused by a delamination. While the screen was viewed directly, the stroposcopic appearance of Figure 12 was not in evidence and appears in the photographic image because of a combination of tire speed, image rate and camera exposure time.

FIGURE 5
SECTION OF TIRE REVEALS FLAW DETECTED IN FIGURE 4

FIGURE 6
SETUP FOR PASSIVE TIRE TEST EMPLOYS INFRARED MICROSCOPE

Next, the tire was stopped, and the thermogram appeared as shown in Figure 13. Here, the tread is very hot, but the defect appears in the upper portion of the cooler arc.

ADVANCED THERMOGRAPH ARRANGEMENTS

The previous apparatus permitted any desired portion of the tire to be viewed, but it did not permit simultaneous viewing of the tread and both sidewalls. An arrangement that permits this is shown in Figure 14. The addition of two first surface mirrors identified as the "auxiliary mirror system" to the T-101 infrared camera adds considerable information to the display with only modest cost and no increase in equipment complexity. The diagram includes a typical thermogram developed by this apparatus. With the tire rotating on the dynamometer, it is possible to "strobe" or stop the hot spot on the screen by adjusting tire speed. The light spots shown on the thermogram portion of Figure 14 are defects resulting from impact tests on the tire.

CONCLUSIONS

Infrared nondestructive testing of vehicle tires is being conducted by the U.S. Army Tank-Automotive Command, the National Bureau of Standards, Comstock & Wescott, Armstrong Tire, Barnes Engineering Company, AGA Corporation, Smithers NDT Laboratories, Wright-Patterson AFB and others. This work indicates that IR NDT of tires has a versatility and speed not approached by other methods. It is expected that tires with enhanced safety will result because of increased research in failure phenomena, improved tire design, and more effective production testing of tires.

It should be noted that the present work has demonstrated feasibility, but the total capabilities of IR NDT of tires have yet to be explored, and considerable research and development is required.

ACKNOWLEDGMENT

The author wishes to thank Mr. Paul Vogel of the Army Materials and Mechanics Research Center for his assistance in the preparation of this paper, and for the performance and reporting of much of the work described.

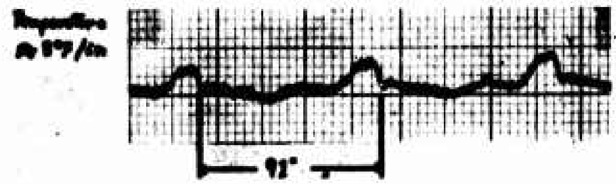

FIGURE 7
PASSIVE TEST RECORDER TRACE REVEALS LARGE AND SMALL DEFECT IN TIRE TREAD

FIGURE 8
SECTION OF TIRE REVEALS LARGE FLAW DETECTED IN FIGURE 7

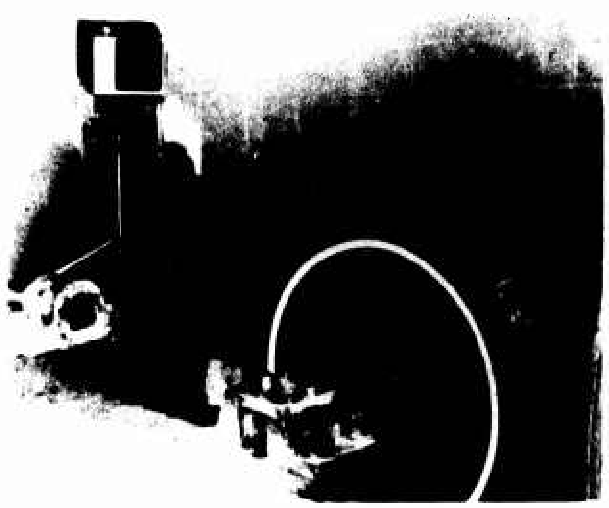

FIGURE 9
EQUIPMENT SETUP FOR REAL-TIME TIRE TEST EMPLOYS REAL-TIME INFRARED CAMERA

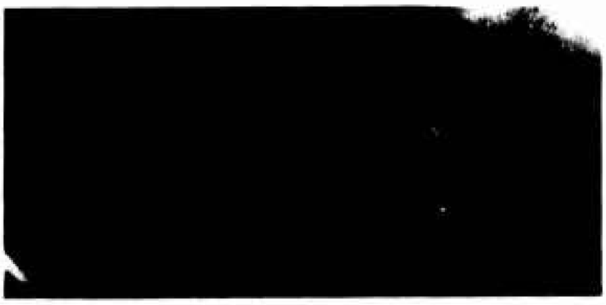

FIGURE 10
THERMOGRAM OF TIRE ON TEST STAND INDICATES IT IS AT UNIFORM AMBIENT TEMPERATURE BEFORE TEST BEGINS

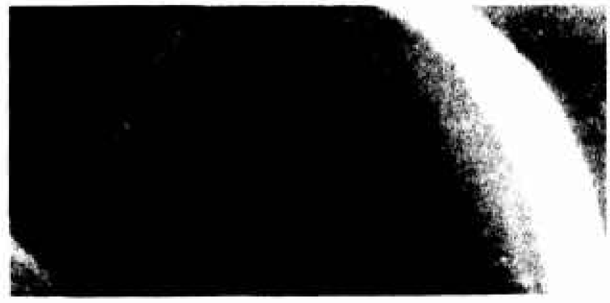

FIGURE 11
THERMOGRAM OF SAME TIRE AFTER ONLY SECONDS OF RUNNING UNDER LIGHT LOAD SHOWS CONSIDERABLE TREAD HEATING

FIGURE 12
THERMOGRAM OF SAME TIRE AFTER 2 MIN OF RUNNING SHOWS SIDEWALL HEATING DUE TO DELAMINATION

FIGURE 13
THERMOGRAM OF SAME TIRE STOPPED. HOT AREA ON SIDEWALL SHOWS EXTENT OF DELAMINATION

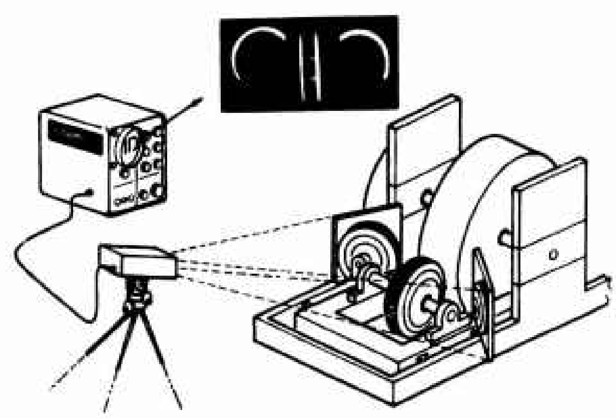

FIGURE 14
EQUIPMENT SETUP SHOWING REAL-TIME INFRARED CAMERA AND AUXILIARY MIRROR SYSTEM FOR SIMULTANEOUS EXAMINATION OF TIRE TREAD AND BOTH SIDEWALLS

INFRARED EMISSION AS A TIRE DIAGNOSTIC AID

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ABSTRACT

The presence of localized defects in tires generally produces an excess infrared emission in the vicinity of the defect. Mechanisms producing such excess emission and methods of measuring and displaying these excess emissions are described and illustrated.

It is well known that certain defects in tires produce localized hot spots in the form of temperature differentials in the vicinity of the defect when the tire is rotated under load. Thermal conductivity from the hot spot to the surface of the tire then produces a region of slightly higher surface temperature which can be detected by an excess of infrared emission.

The effect can be easily seen by inducing one or more defects in a tire by subjecting it to severe stresses and strains on a plunger machine of the type shown in Figure 1. The infrared signature of a G78-15 tire with such an induced defect is shown in Figure 2, where a pronounced spike was present at the point of impact with the plunger. The stresses and strains used were such that breaking of belt and/or ply cords could be heard during the application of the stress, so that these spikes were apparently related to induced defects.

Unfortunately, these defect signals were superimposed on a fluctuating background and resulted in what appeared to be a low signal-to-noise ratio. Closer examination of the background showed a periodicity and indicated that it could not be attributed to random noise. As shown in Figure 3, expansion of the oscilloscope time scale in a region between the spikes confirmed the periodicity. Figure 4 illustrates the signature from the same part of the tire after removal of the tread pattern by grinding. It is clear that most of the background in Figure 2 was caused by the tread pattern where temperature differentials between ribs and grooves can easily reach 20°F.

Since the infrared signature produced by the tread pattern was of no interest in studying the premature failure of a tire and its presence detracted from resolving the defect-induced spikes, two methods of suppressing the unwanted background were used. One was to process the signal through a nonlinear amplifier [1]. The difference in the defect pattern with and without such processing is shown in Figure 5.

Quite apart from the defect spikes, the background signal showed slow variations from the baseline. Such variations can be caused by the sensor receiving radiation from points whose distance from a groove may fluctuate as the tire rotates or by other constructual defects such as out-of-roundness. Such slow small fluctuations can be studied by suitable modification of the response time of the amplifier. On the other hand, the same effect with a very large increase in gain can be obtained by using a newly developed infrared detector based on poled polyvinyl fluoride film [2].

The infrared signature of another tire, before and after road impact with a 4-in. blunt plunger, 3/4-in. diameter, at 40 mph, obtained by this technique is shown in Figure 6.

After impact this tire was loaded against a roadwheel and run for 1 hr at 60 mph. This produced no significant change in the infrared signature, and the tire survived a run of 3000 mi without any evidence of failure.

The time dependence of plunger-induced spikes of various degrees of severity is shown in Figures 7 and 8. Reading left to right, the spikes shown in Figure 7 were produced by plunger loads of 1000, 1500, 1700 and 1700+ lbs, respectively. The spike associated with the 1000-lb load was higher than that produced by the 1500-lb load because the durations of the loads were 5 min and 30 sec, respectively. The spike produced by the 1700-lb load was associated with an audible signal indicating the breakage of a single cord within a few seconds after reaching full load when it was retracted, while the spike produced by the 1700+ lb load corresponded to an audible signal indicating that some ten cords were broken in rapid succession before the load could be retracted.

When this tire was driven under load at 60 mph for 3 hrs, all spikes gradually decreased in height. On increasing the speed up to 90 mph all except the 1700+ lb spike vanished into the background and were permanently annealed out. In contrast with this, as shown in Figure 8, the 1700+ lb

FIGURE 1

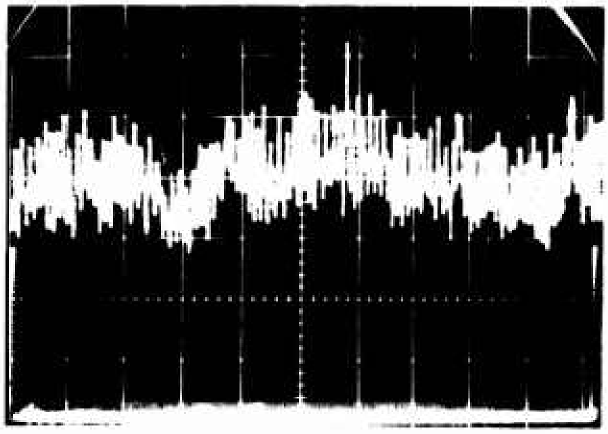

FIGURE 2

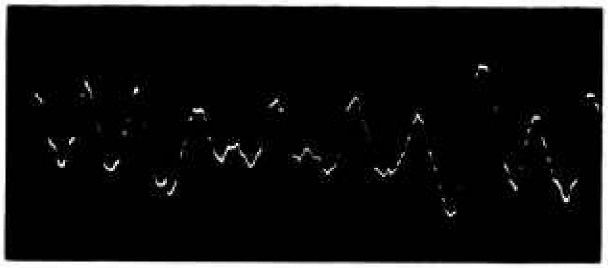

FIGURE 3

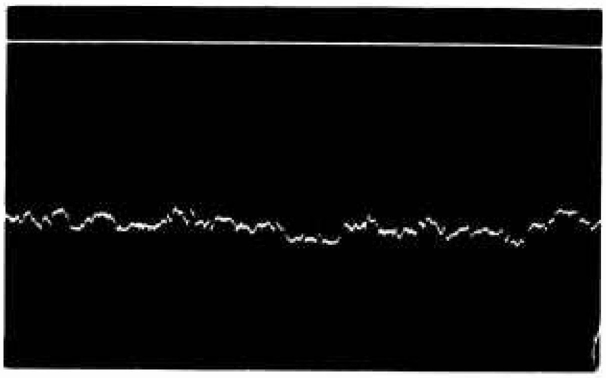

FIGURE 4

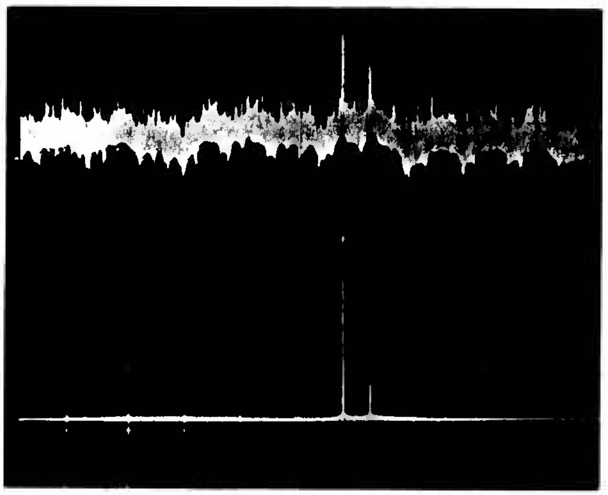

FIGURE 5

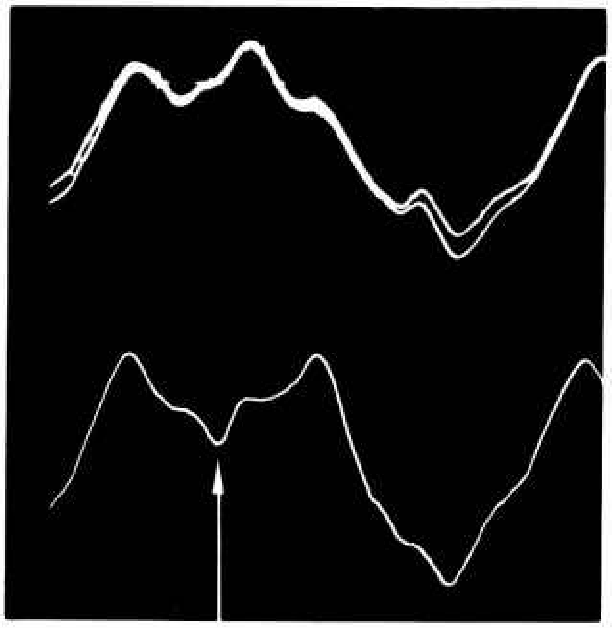

FIGURE 6

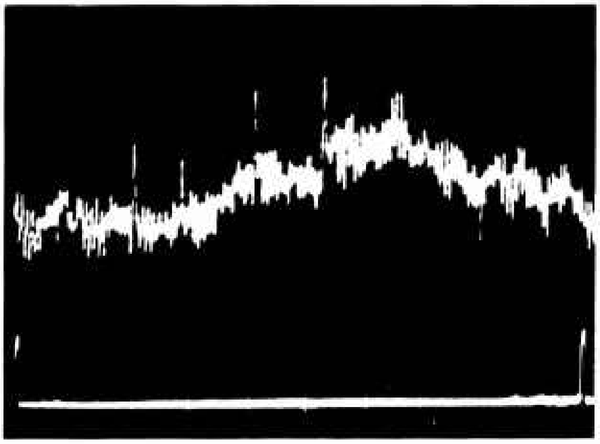

FIGURE 7

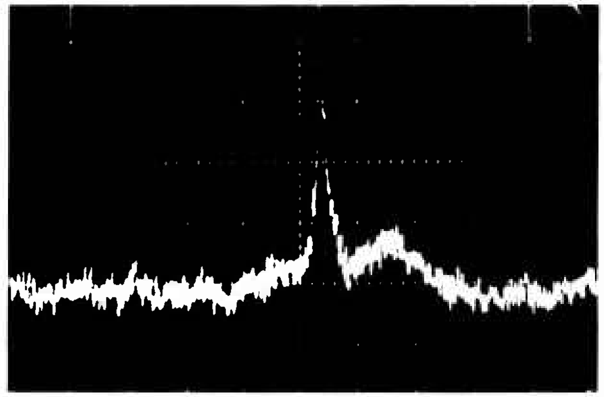

FIGURE 8

spike grew rapidly. In order to retain the signal on the scale, the gain of the amplifier had to be reduced by a factor of 2.5 so that the spike in Figure 8 had grown to 8 times its original size. At this time a visible tread-sidewall blister could be seen at the damage site. The blister exhibited the progressively increasing ellipsoidal structure characteristic of an adiabatically compressed gas bubble [3].

In contrast with this, we were unable to detect any infrared signal due to solid foreign bodies in the form of small cylinders having a diameter of 1/8 in. embedded in and *cemented* to a rib.

In conclusion, we may say that infrared techniques provide a sensitive and powerful method of observing certain types of abnormalities in tires and for studying their thermal characteristics, but much more work and experience is needed before an infrared signature of a tire can be related to the probability of premature failure except in the case where the infrared signal shows a finite growth rate.

The authors would like to thank Dr. F. C. Brenner for his interest and many instructive discussions in this work and for his help in some of the interpretation of the signals in relation to premature failure.

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2. Cohen, J., Edelman, S., and Vezzetti, C. F., Symposium Trans. Int. Conf. on Electrets, Miami Beach, Florida, Oct. 8-13, 1970 (Electrochem Soc.).
3. Winogradoff, N., Rubber Age **103** (12), 53-54 (December 1971).

INFRARED FOR DYNAMIC NDT OF PNEUMATIC TIRES

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ABSTRACT

To date, most infrared nondestructive testing of tires has been concerned with either measuring the average temperature of tires or rotating the tire at relatively low speeds to obtain the temperature distribution. Using recent advances in infrared technology, a radiometer has been specifically designed for a real-time IR NDT of tires while they are undergoing dynamic tests. Some results of tests made with this type of radiometer on test wheels and on the road are presented. The interpretation and significance of these results are discussed.

Over the years many methods of testing tires have been developed. The physical, nondestructive tests are particularly varied. They include such methods as X-ray analysis, holography, ultrasonics, and contact thermometry. Almost all of these have achieved some measure of success for static testing. However, when applied to dynamic testing (i.e., testing a loaded, rotating tire), these methods become less effective as the speed of rotation increases. And yet, testing a tire under dynamic conditions is preferable since this more closely simulates the actual conditions of usage. Of all the nondestructive testing methods, infrared radiometry (the measurement of emitted infrared radiation) has recently proved to be the most effective method for the real-time dynamic testing of tires under both laboratory and field conditions. And because no slow recording mechanism (such as film) is required, the tire can be monitored at any speed.

Since the tire surface has fairly uniform emittance properties, infrared radiometry gives a measure of the surface temperature, a parameter related to many important tire properties. Temperature data is usually gathered in two forms: (1) the average temperature around the circumference, and (2) different information about the basic properties of life expectancy of a tire. For example, the average temperature of the tire indicates how well the tire has been designed and the quality of the materials from which it was constructed. Generally, the lower the average running temperature, the longer is the expected lifetime. On the other hand, the gradients or anomalies along the circumference of a tire result from deficiencies in the manufacturing process for either an individual tire or for an entire batch. They also indicate the localized defects or flaws produced in a tire during use and provide a method of observing how the defects behave with time.

A tire's temperature can be raised in two ways. One way is to use an external source, such as a quartz lamp, to heat a stationary and/or unloaded tire. The temperature gradients then result from differences in the thermal conductive properties and heat capacities of different parts of the tire. Usually only the gross internal nonuniformities and defects are observable by this method. Alternatively, if the tire is rotated under load, the tire itself generates heat by means of the conversion of kinetic energy into heat. The resulting thermal gradients and anomalies are then mainly due to differences in the elastic properites of the parts of the tire. These differences in elastic properties are directly related to a wide variety of defects such as separations, broken cords, poor splices, out-of-roundness, imbalance, and poor adhesion between plies. This latter method has been shown to be much more effective for nondestructive testing.

The instrument which detects the emitted radiation without contacting the tire is called a radiometer. Basically a radiometer consists of optics, detector, electronics, and a display The optics are the mirrors and/or lenses which collect the emitted radiation and direct it onto the detector. In some cases various apertures and filters may be used to limit the radiation received by the detector. The detector is simply a transducer which responds to the radiation incident on it by producing an easily processible signal. The signal can be mechanical, electrical, or even optical in nature. Usually the electrical signal is preferred because of the extensive instrumentation available for processing it. The electronics provides the electrical power to the detector and also amplifies and processes the signal from the detector, putting it into a form more meaningful to the user. Finally, the display presents the processed signal in a way which the user can most beneficially store or use it. Therefore, a wide variety of

*The author was with Sensors, Inc., at the time of the presentation but is now with Philco-Ford Corp., Newport Beach, California.

displays are available, such as strip charts, magnetic tape, oscilloscopes, horns, lights, and meters.

The most widely used infrared radiometer system for detecting flaws in tires undergoing dynamic testing is that manufactured by Sensors, Inc., illustrated in Figure 1. A room temperature photoconductor is used as a detector. The optics consist of a front-surface ellipsoidal mirror. A mirror was chosen in preference to a lens because of the better optical efficiency at the longer wavelengths. For the temperature range of interest most of the emitted radiation from the tire is at these longer wavelengths. To amplify the signal from the detector, an AC-coupled amplifier is used with a bandpass sufficient to work with tire speeds from about 20 mph to 1000 mph. A low frequency version for speeds from 5 mph to about 100 mph is also available. The detector, optics, and amplifier are housed in a rugged iron and steel case (or head) specifically designed to withstand the shock from the flying debris of exploding tires (Figure 2). Additional electronics such as power supply and processing electronics are housed in a separate case located some distance away from the tire and radiometer head. The display is a CRT of an oscilloscope. This method of display instead of a hardcopy was chosen to facilitate continuous monitoring of the tests. To increase the usefulness of the systems, Sensors has also made available an automatic monitoring and alarm system. This system compares the hot or cold spots of the thermal profile to preset upper and lower limits. When these limits are exceeded, a variety of responses is set in motion, such as activation of a relay to shut down the test, activation of a camera to take a picture of the CRT face, and the sounding and lighting of alarms.

Prior to discussing the oscilloscope traces obtained from actual tire defects, one should examine the drawings* of Figures 3 and 4. These represent the typical shapes to be expected for the temperature-difference profiles from various defects in tires undergoing dynamic testing. The shapes are modified somewhat depending on the location of the defect with respect to the circumferential strip being observed.

Figures 5 through 12 are oscilloscope traces obtained under laboratory and field tests. The interpretation of the traces and the defects that produced them are discussed below.

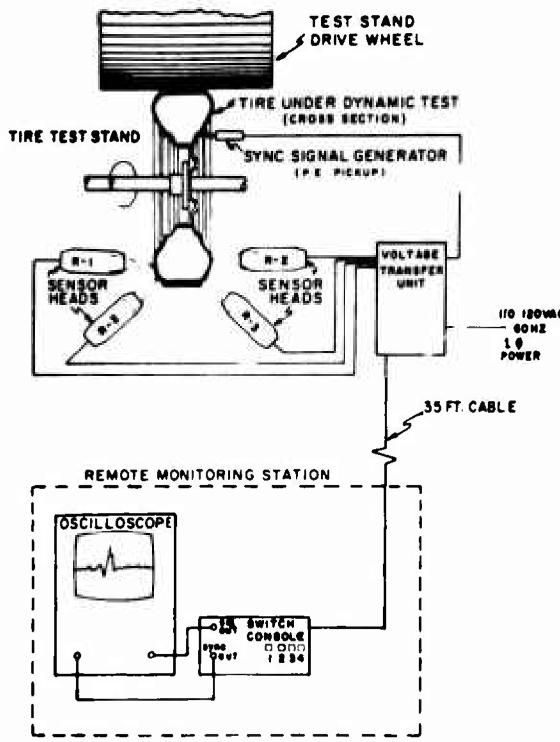

FIGURE 1
DIAGRAM OF TIRE DEFECT SENSING SYSTEM

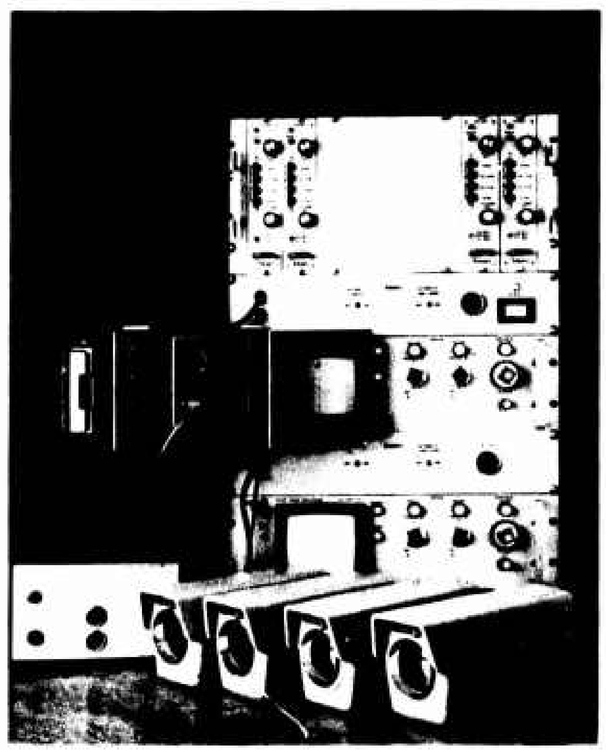

FIGURE 2
AUTOMATED SYSTEM

*By permission of the author of "An Infrared Diagnostic Technique for Evaluation of Automotive Tires," D. Wilburn, Technical Report No. 11154, U.S. Army Tank-Automotive Command, Warren, Michigan.

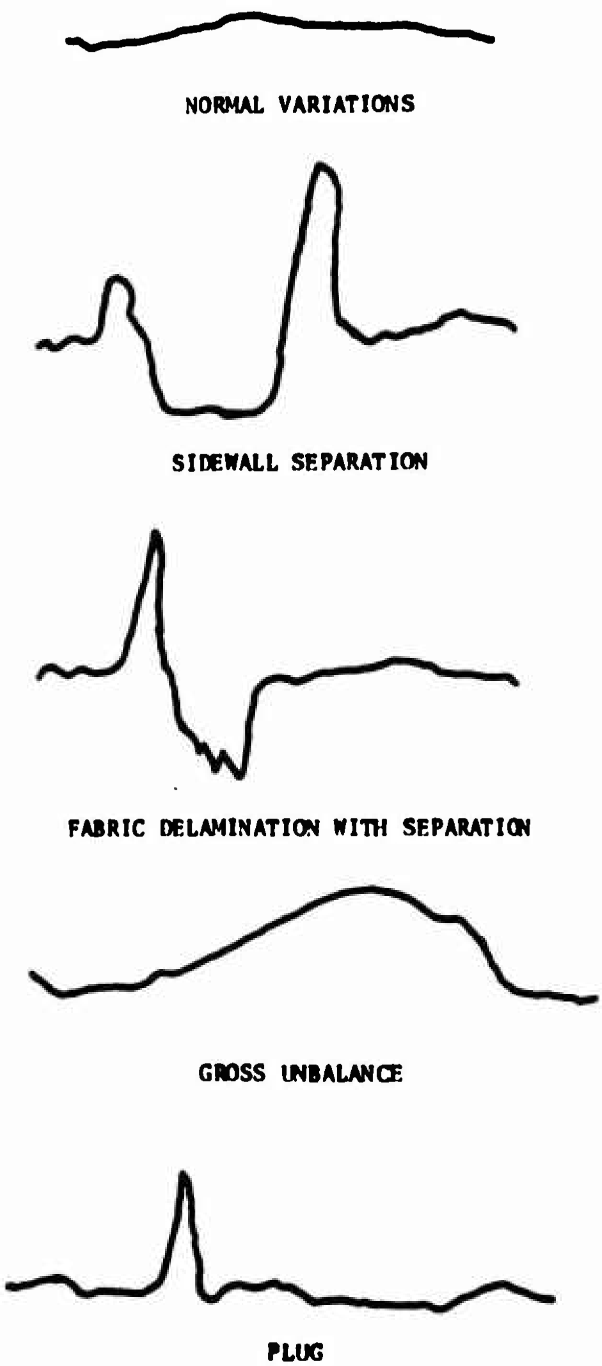

FIGURE 3
TYPICAL THERMAL PROFILES

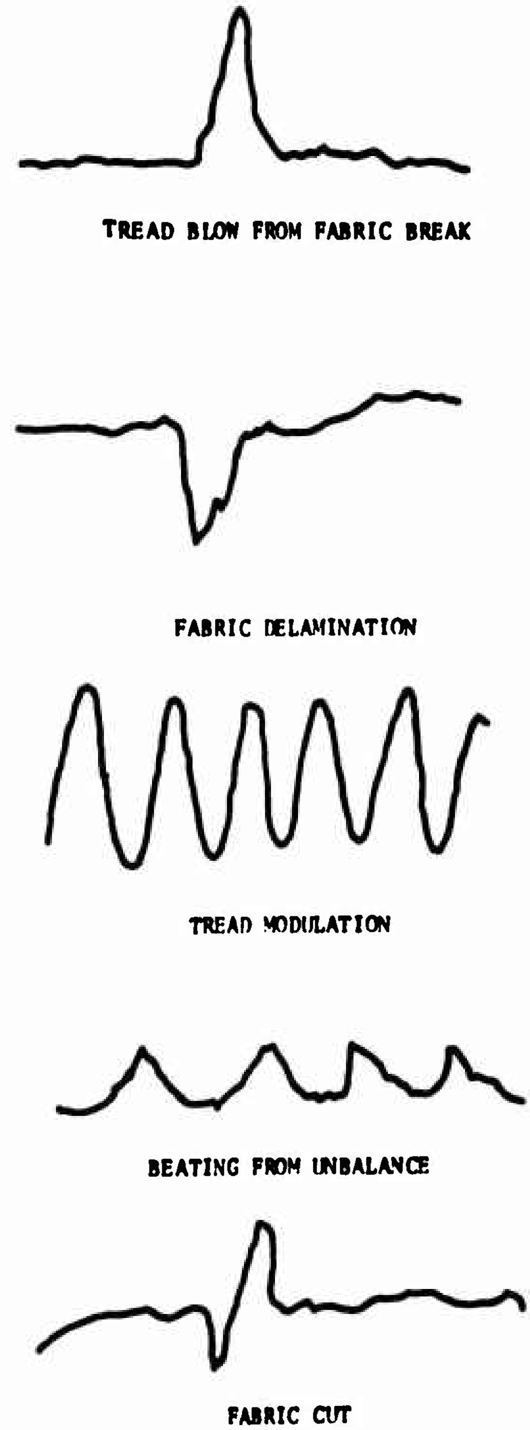

FIGURE 4
MORE THERMAL PROFILES

Figures 5 and 6. These are traces from a good tire, each vertical division corresponding to about 0.5°F. Figure 5 is the temperature difference (from the average) as measured along the sidewall. Note that by comparison with later traces the temperature variations here are quite small, the trace being relatively smooth. Figure 6 is from the same tire, but now we are looking at the tread surface. Of interest here is the "grassy" nature of the trace. Individual grooves in the tread are what produce this type of structure. The hotter spikes are the depths of the grooves and the cooler spikes the top of the tread.

Figure 7. A debond was produced by introducing a 1-in. diameter piece of polyethylene film between tread and ply. The two hot spikes separated by a cool region which is the debond area characterize both a naturally occurring debond and an introduced one such as this. As this defect develops and grows worse, the hot spikes grow even hotter, sometimes by a factor of 20 or more. Also characteristic of a debond or separation is the higher temperature of the trailing spike.

Figure 8. Lack of proper adhesion, a fabric delamination, produced the cooler anomalous region here. This type of defect produces a cooler region with, in some cases, a warm spike within it. When the delamination results in separation, the trace is modified as shown in Figure 3.

Figures 9 and 10. In this tire a plunger was used to break cords and, as a result, cause separation without puncturing the tire. The traces were obtained after different running times – Figure 9 after about 10 min and Figure 10 after about 30 min. One can see how the defect has grown in width as well as intensity within a period of about 20 min. The sharp, hot spike is, of course, the broken cords and separation. Also apparent in the figures is the broad warm hump due to an imbalance or out-of-round condition of the tire. Note that the magnitude of this part of the signal has not changed in the time interval.

Figure 11. This trace was obtained from a tire which had a cut on the inside of the carcass. The tire was mounted on a vehicle, and the defect was not known to be present until after the test.

Figure 12. This tire was also monitored while on a vehicle. The very large spike was produced by a plug in the tread.

In conclusion, it is apparent even from the few examples shown here that the temperature-difference radiometer is an effective tool for the dynamic nondestructive testing of tires. It has the unique capability of being able to provide real-time information on the development of defects in pneumatic tires. By dissecting tires showning regions of thermal anomalies, the shape of the signal can be correlated with the type of defect. And by studying the temporal behavior of the signal, one can accurately predict the time of failure. Therefore, what is required for successful utilization of the system is that actual thermal data on specific thermal anomalies obtained by the user.

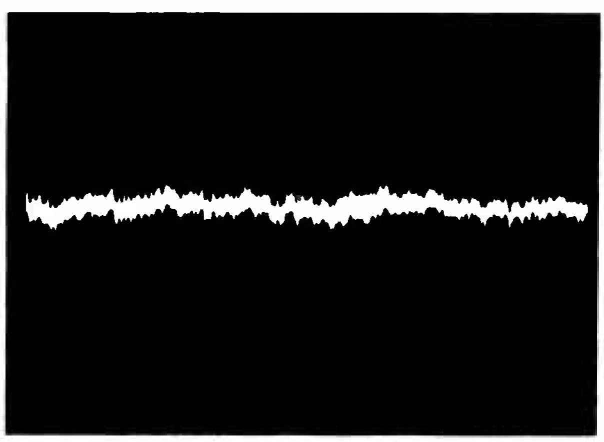

FIGURE 5
GOOD TIRE, SIDEWALL AREA

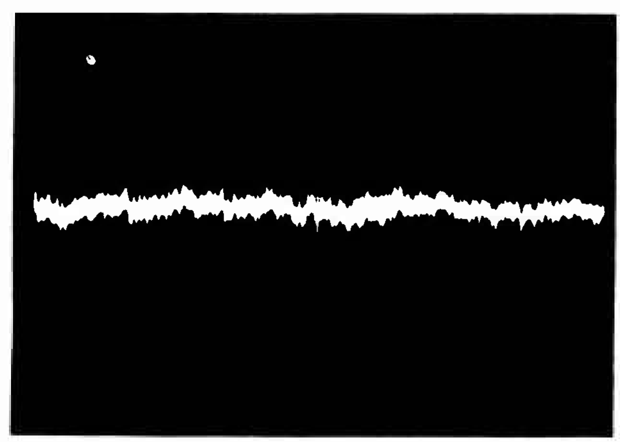

FIGURE 6
GOOD TIRE, TREAD AREA

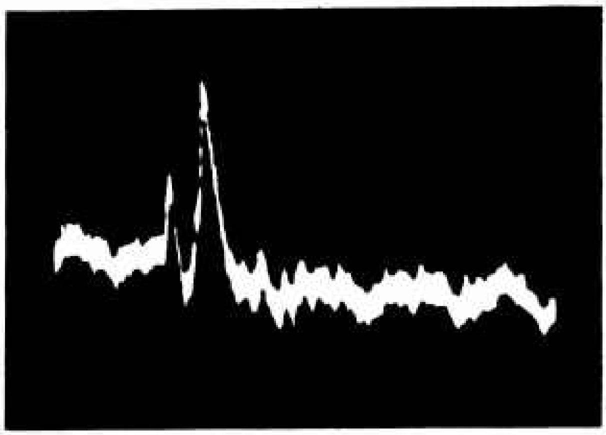

FIGURE 7
THERMAL PROFILE OF DEBOND

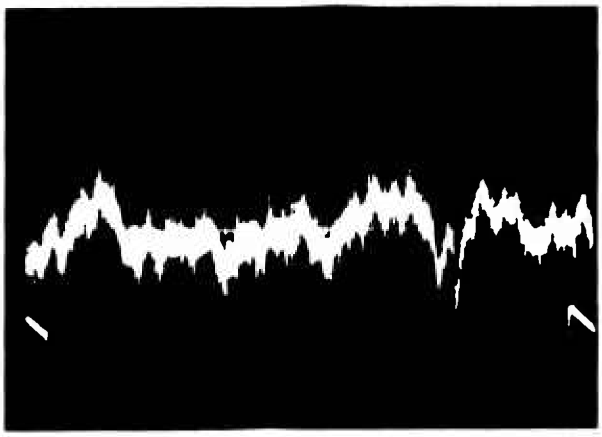

FIGURE 8
FABRIC DELAMINATION

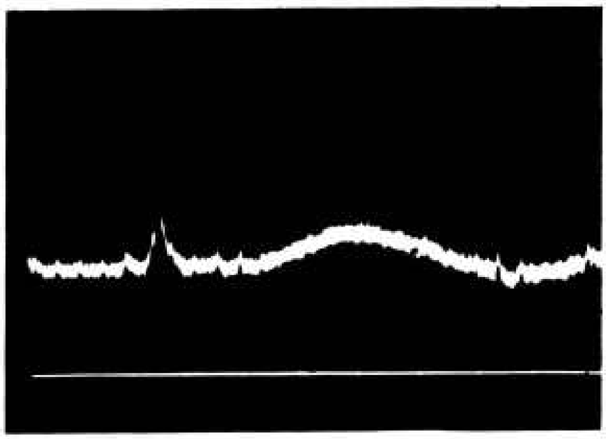

FIGURE 9
BROKEN CORDS AND SEPARATION

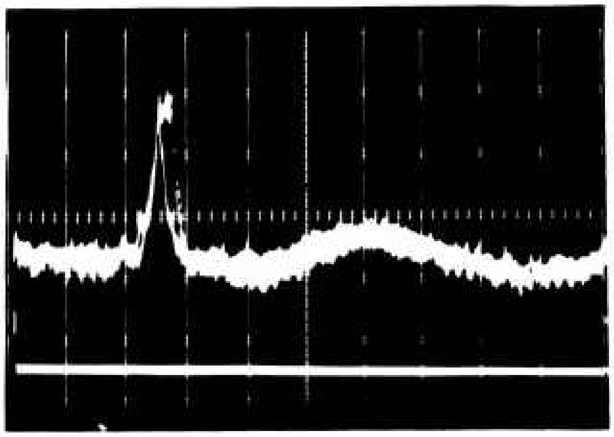

FIGURE 10
BROKEN CORDS AND SEPARATION AT LATER TIME

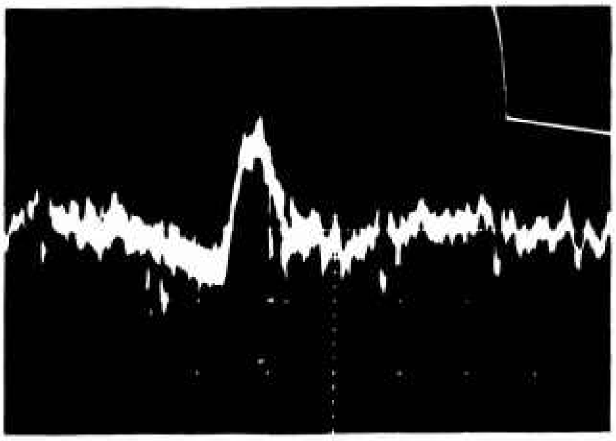

FIGURE 11
INTERNAL CUT IN CARCASS

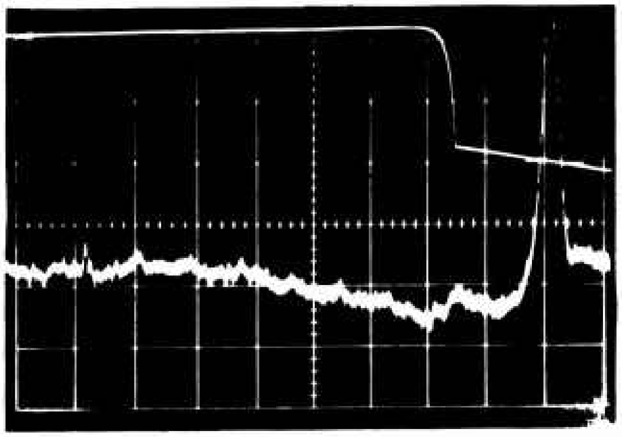

FIGURE 12
PUNCTURE REPAIRED BY PLUG

CHAPTER VI – X-RAY TIRE TESTING

AUTOMATIC X-RAY SYSTEMS FOR TIRE INSPECTION

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Picker, Inc.
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ABSTRACT

With the increasing demands of automotive safety standards and the recent requirements to control belted and radial tire constructions, X-ray has progressed from the laboratory to the on-line production control process.

Continued close cooperation between the tire manufacturers and the X-ray equipment development laboratories has rapidly contributed to the state-of-the-art advances in:

1. *Production manipulation and handling of tires reducing inspection time.*

2. *Imaging techniques.*

3. *"Operatorless" automatic video analysis for specified tire construction parameters.*

This paper will review these advances in X-ray inspection systems including theory, concepts, and proven operational systems.

Many of us here today are using X-ray to inspect tires. Some are here today to gather information to justify or consider the addition of this equipment to their facilities. It is for this reason that we feel we should discuss briefly:

1. The merits of X-ray versus holography, infrared, and other nondestructive methods as applied to tire testing.

2. Systems development to give a better insight into advantages of laboratory equipment, low volume testing, compared to high production inspection of tires – in general, the history.

3. A review of the components of an X-ray system. Considerable research has been conducted by the X-ray companies as a result of demand by the tire industry to improve viewing detail, increase the handling capabilities for production control, and automatic image interpretation.

Judging from the number of total installations of X-ray systems worldwide in the tire industry, we must assume that this method of nondestructive testing is the most widely accepted and most beneficial from a qualitative as well as quantitative standpoint. It is evident that X-ray provides analysis with maximum flexibility, from the 10-in. to the giant 10,000-lb OTR (off-the-road) tire (Figure 1) with a minimum of setup (manipulator), and has the ability to detect the majority of constructional abnormalities now confronting the tire industry – this can be an excellent topic for discussion in our later group meetings.

Again, for the benefit of those unfamiliar with X-ray, let's review the components of today's laboratory system.

Figure 2 shows the tire placement between the image intensifier and the directional cone of X-radiation. The 9-in. input phosphor of the image intensifier relates changes in density of the tire construction. A shadowgraph is produced by varying degrees of light from fluorescing crystals. The brightness of this screen is minimal and is given intensification by electronic focus and acceleration to a smaller output phosphor which is directly viewed by optics or a television camera. The tire is rotated and angulated to give full bead-to-bead inspection.

Semi-automatic systems require operator interrogation. Figure 3 shows the requirements for a tire inspection system: the sample being the tire, the manipulator to handle and position the tire, the image produced by either a straight fluoroscope screen or an image intensification device. The evaluation of the tire construction is by the technician. One of the first imaging systems for tires was mounted on a boiler plate for shielding. Viewing was done by direct optics.

What type of constructional abnormalities can we detect reliably with X-ray imaging? There are many, some very unique with the tire manufacturer, but, in general, they can be listed as:

1. Uniformity and concentricity of the bead area

2. "Turnup" height uniformity

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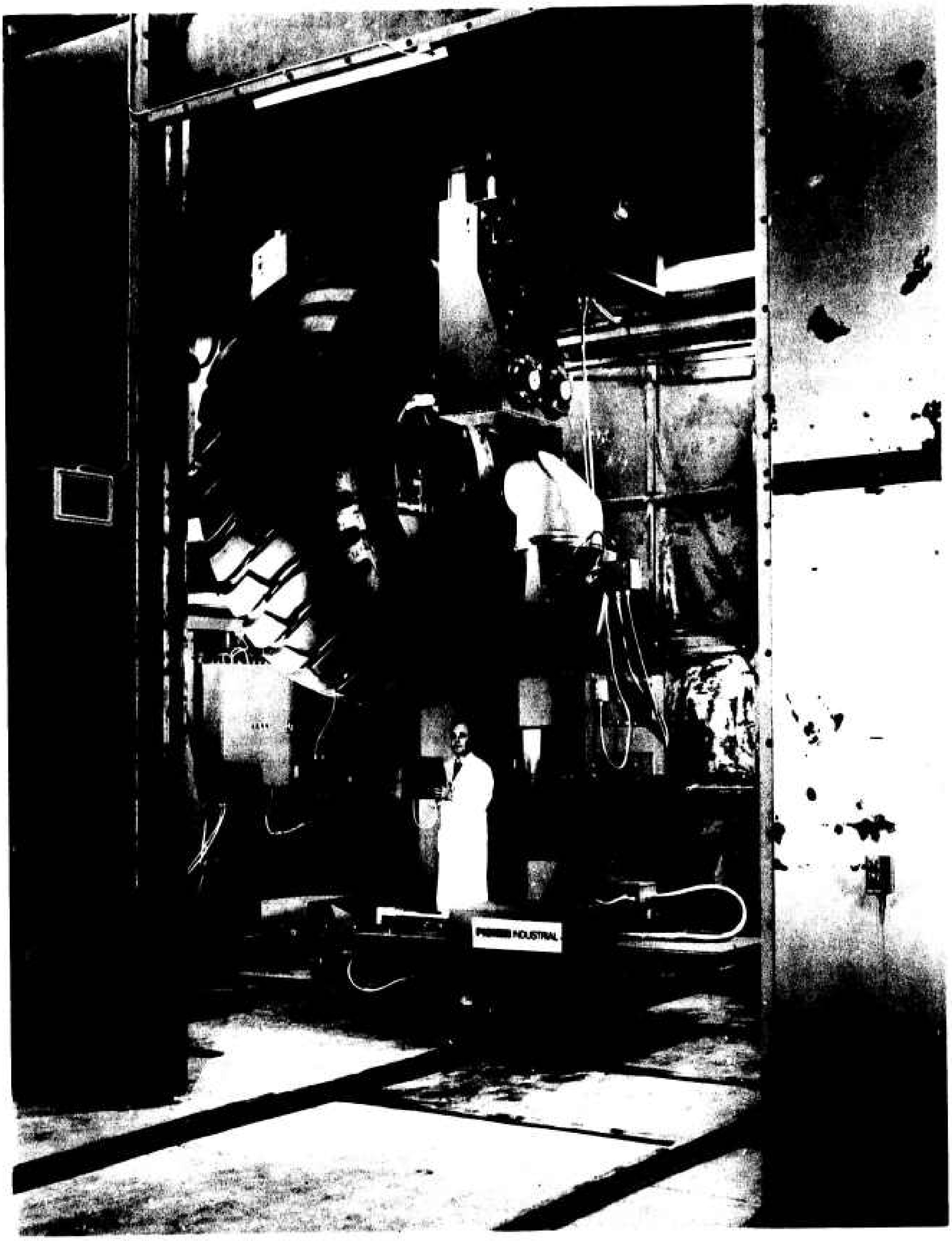

FIGURE 1

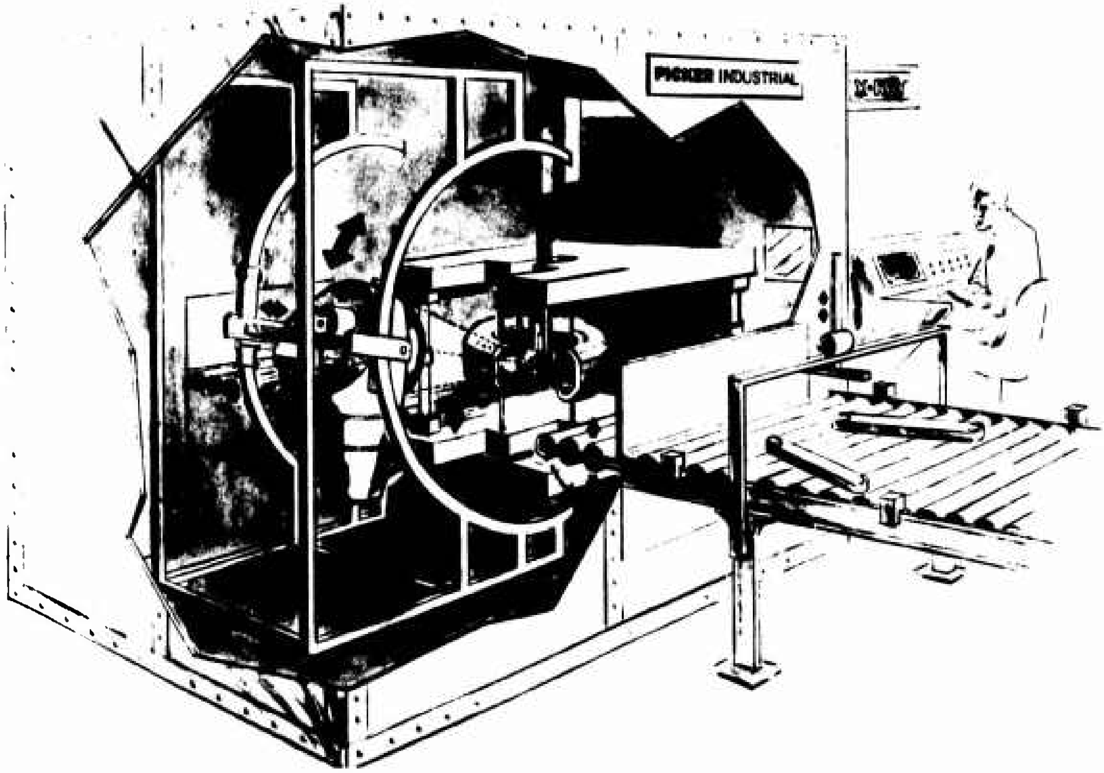

FIGURE 2

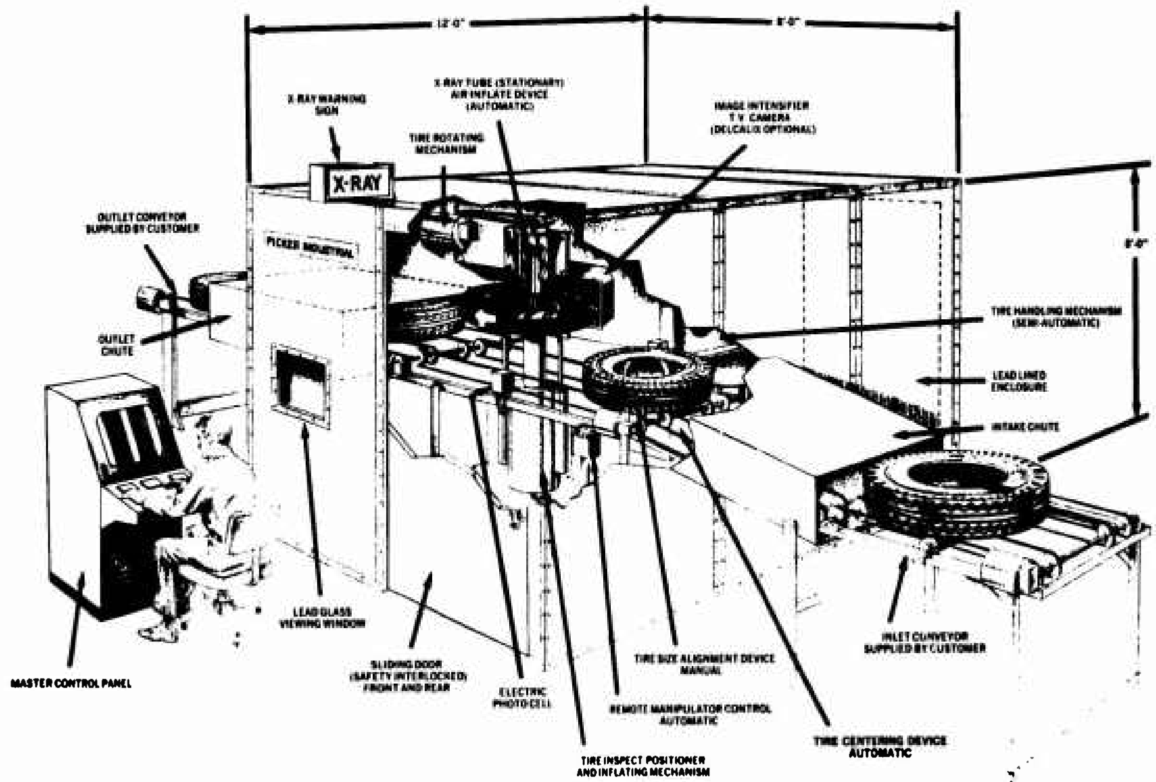

FIGURE 3

3. Cord angle – entire tire

4. Splices – quality and quantity

5. Separation and air entrapment

6. Porosity

7. Inclusions and lack of material

8. Belt positioning: C/L of belts 1 and 2, uniformity of "step-offs" or breaker edges, open splice or heavy splice.

It is my decision not to display monitor images of these conditions. From an ethical standpoint, and considering product identification at a public meeting, this is our position.

The imaging device used should have the flexibility to image all cord materials, regardless of the surrounding rubber chemistry. The exploded view (Figure 4) of the Delcalix shows the most widely accepted system in use today. A definite requirement of a tire imaging system is to be able to change the fluoroscopic screen to enhance the parameters of cord materials and rubber thicknesses. The Delcalix is unique in design, and one of the reasons for its original acceptance was that there was no reduction or absorption of the soft radiation prior to the fluoroscopic screen as happened in the first image intensifier tubes with glass envelopes. It is flexible in imaging all materials – rayon, polyester, nylon, fiberglass, the new fiber "B", and, of course, the easiest, steel. I might add *not* with equal resolution. The ability to meet the changing technology of cord materials must be considered. If the situation presents itself to inspect 9 in. of tread rubber through four steel belts, the imaging system must have the inherent flexibility.

Most universal tire machines incorporated the directional X-ray tube, which had to be inserted between the spindles, and the entire tube housing had to be rotated about a pivot point synchronized and tracked with the imaging device. With this tube usage, it was necessary to use a spindle mounting manipulator for the tire (Figure 5).

With the development of the Lighthouse tube, sometimes referred to as the roto-beam X-ray tube, only the X-ray tube insert is moved within the stationary housing. With the Lighthouse tube, it is possible to insert the X-ray tube into the torus of the tire, and provide uniform geometry of imaging from one bead to the opposing bead (Figure 6). With this tube it is possible to measure both sidewalls and bead areas with equal magnification – no geometry compensation as with the directional tube head (Figure 7).

One of the first installations to incorporate this similar type of tube housing was the aircraft tire inspection system.

What led to the development program for volume, high production X-ray machines, rather than the universal, highly flexible type machine shown in Figure 8? For most tire plants, this is still the most accepted today.

This was probably the first venture into the design of a system to inspect tires on a production basis. By gravity roll feed the tire is indexed into position for rotation to inspect only one selected sidewall area. The operator makes an accept/reject decision and the tire exits. It was now apparent that X-ray inspection was gaining acceptance into the production areas of tire manufacturing.

The production X-ray system design in Figure 9 was specified by an overseas manufacturer for four systems. The system was to have the ability to conveyor load and unload in the horizontal, but be able to intermix passenger and truck tires in the bead range of 12 to 24 in. Two systems were supplied to inspect belt runout and two for a complete bead-to-bead scan. In operation, the horizontal tire was "dumped" from upper conveyor into the vertical acceptance compression chute (to intermixed ODs), and the standard universal manipulator spindles and X-ray tube would position with the motor-driven floor track into the bead ID for expansion and spreading (see Figure 4). The tire would then rotate for operator viewing. The lessons learned from this engineering and design experience were:

1. Spindles and mechanical spreading of the beads were not production oriented; they were too time-consuming and had too many motions and moving parts.

2. Centerline of rotation moving on spindles was not conducive to accurate centerline rotation for automatic electronic analysis in future.

After considerable marketing research into the requirements of the tire industry, the following design guidelines were presented to engineering for development of a production X-ray manipulator:

1. System would have load/unload cycle time of 8 to 10 sec.

2. Minimal floor space including shielded enclosure.

3. Straight feed-through design for minimum of moving parts.

4. Spreading of beads would be uniform at all areas of tire while under viewing.

5. System not be limited just to *belts* but, instead, a complete bead-to-bead inspection capability (Lighthouse tube).

6. Provide a near-perfect centerline of rotation of the tire while viewing so as to have future ability to analyze the monitor image electronically.

7. Provide a manipulator base support which would remain constant and that would not contribute inaccuracies to the tire-positioning device positioned to the bead which was to be referenced.

8. Provide an image of both bead areas utilizing the central axis of the radiation beam relative to the center of the imaging device.

Figure 10 is a view of the first prototype AID (air-inflated device) showing the relatively small area of floor space consumed and the inflated tire in position ready for inspection. This view, of course, shows the imaging system directed at the tread area for belt inspection. Needless to say, there is normally a radiation shield around the system, and the operator console does not appear as shown – this was a prototype. The tire is dropped into the manipulator from a horizontal conveyor, through the square bar stock frame (below the word "tire" in the photograph), and, after inspection, deflated and released through the exit tunnel on the lower left.

Figure 11 shows the Lighthouse tube in storage in the rim – bead range 10 to 16 in. The rims presently in the field are manufactured of plastic and have excellent wear qualities, contributing a minimum of degradation to the image of the bead. After the tire is positioned and inflated, the Lighthouse tube is extended to the exact centerline of the tire; the beam rotation device is pictured, synchronized with the scanning overhead Delcalix. Since the X-ray tube is now extended into the centerline of the tire, by means of a unique design, the eccentric rims drop so as to insert the Lighthouse X-ray tube into the torus of the tire. Combining the exacting geometry of the Lighthouse tube with the perfect geometry of inflation, the tire is almost an arc, and we have an ideal inspection presentation. Bead-to-bead is not a requisite; the system can be programmed for only one specific area, or, by means of a cam setting on the Delcalix scan arm, it can be programmed.

Presently we are building four production systems to satisfy the demand for a highly flexible and universal system to inspect tires in the bead range of 10 through 27 in. to a maximum of 750 lb intermixed, bead-to-bead. This machine will have complete automatic intermix, OD and ID, capability using a Lighthouse X-ray tube. The design incorporates eight spindles (four top, four bottom) to stabilize and, with some tires, to spread the beads, in a horizontal conveyor presentation. We will not recommend this machine for future automatic image analysis.

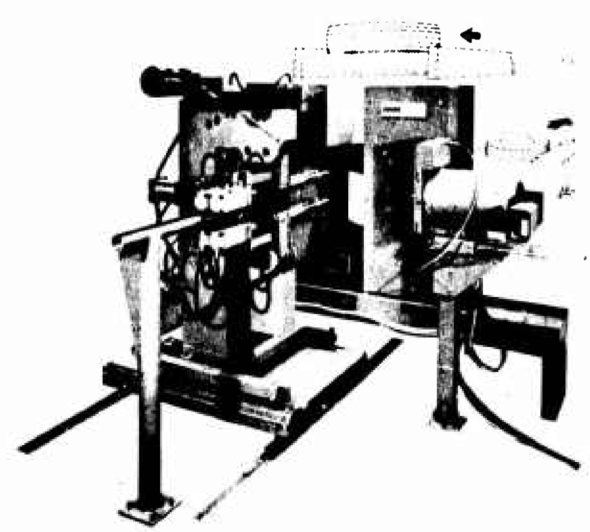

FIGURE 4

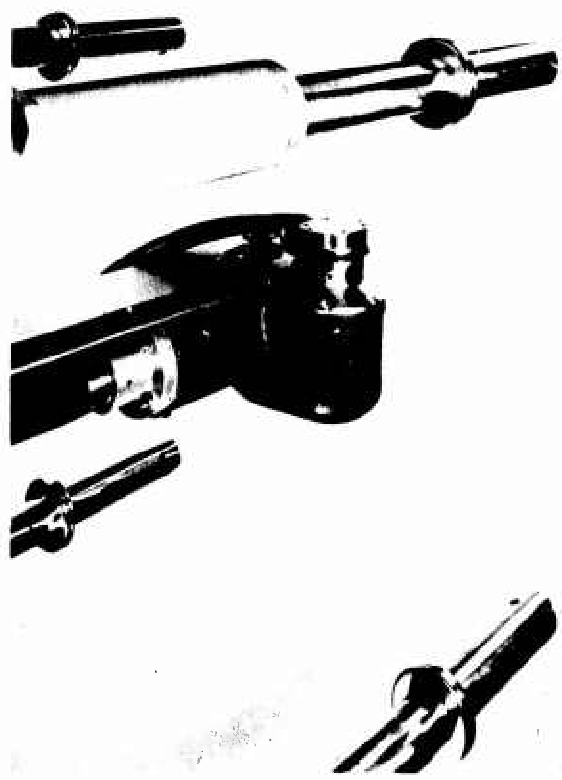

FIGURE 5

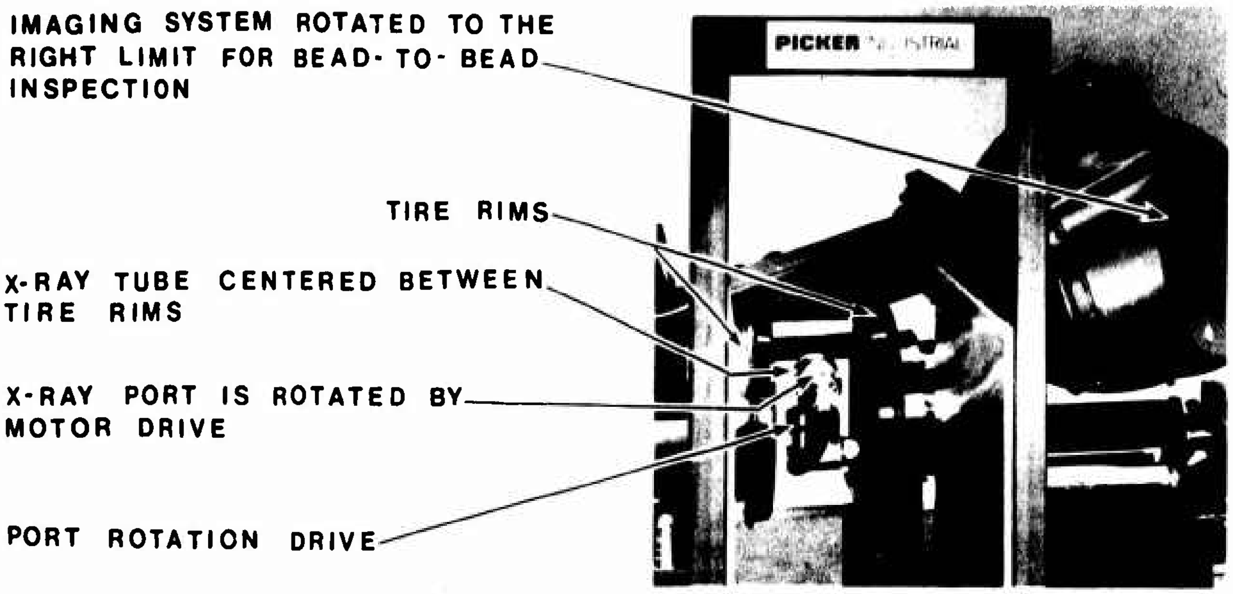

FIGURE 6

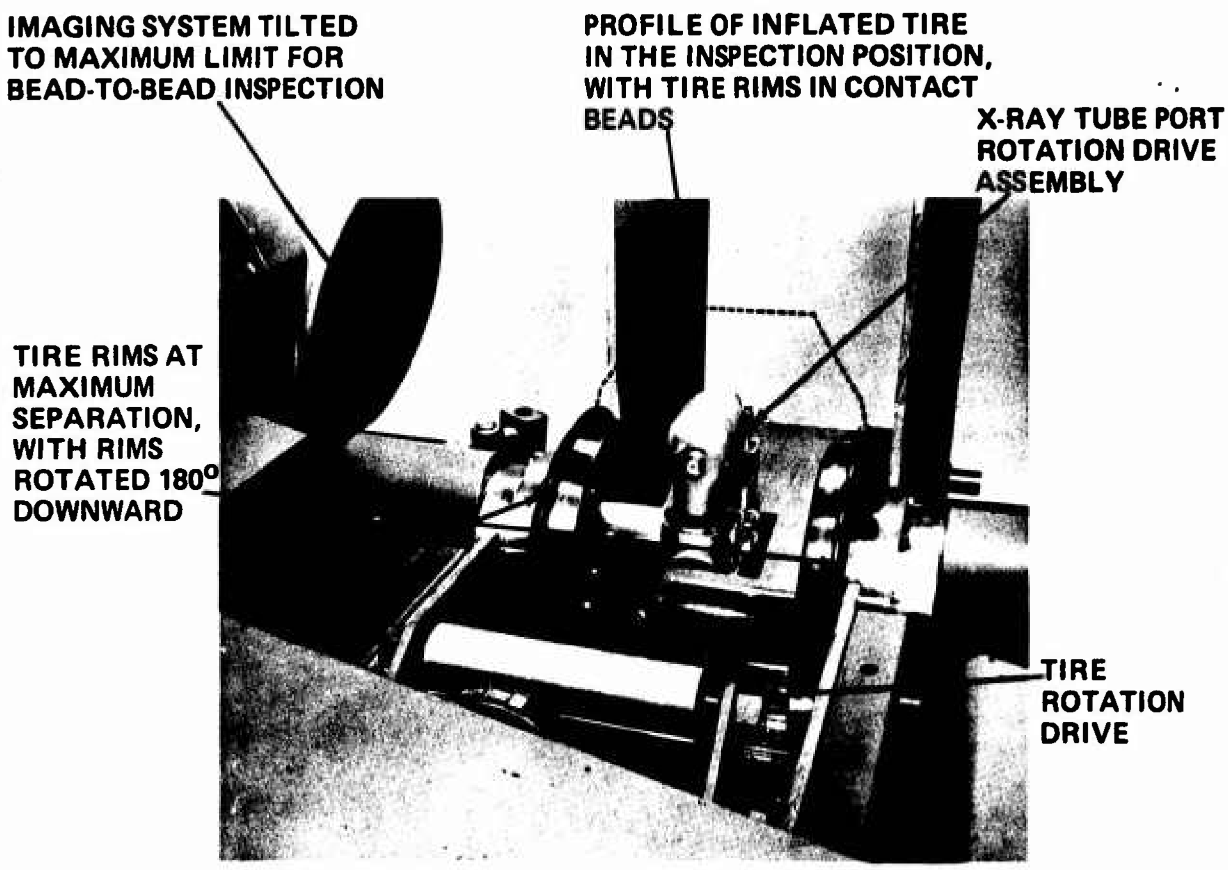

FIGURE 7

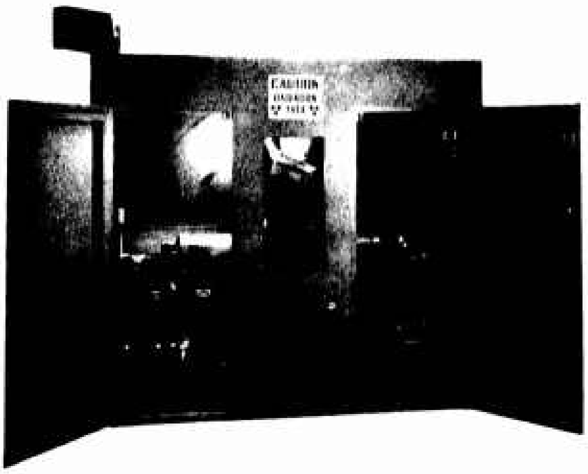

FIGURE 8

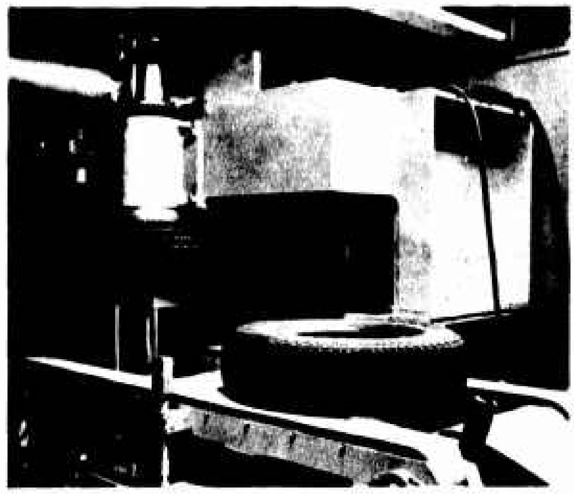

FIGURE 9

Automatic systems is referred to very loosely. *Automatic*, as applied to production tire X-ray systems, has in the past referred to handling and manipulator design, but now it appears very feasible to analyze the dynamic image automatically for abnormalities of construction in the tire.

It has been our own theoretical experience, and actual experience in supplying automatic industrial systems on applications other than tires, that the television electronic logic by far holds the most promise for auto inspection. From a cost standpoint, ability to rapidly intermix tire types and change parameters, it outweighs other methods.

With the increased use of steel cord, the contrast differential between the rubber and the cord is excellent, providing more signal-to-noise ratio and, consequently, more sensitivity. The use of steel will promote the development of auto image analysis. The individual belt cord endings in a slow rotational view, to the electronic scan line, interprets with confusion because they are providing noise. To eliminate this, and reduce the noise, we rotate very rapidly and obliterate the endings for an image to the eye – uninterpretable, but excellent electronic data. High rotational speeds on a near-perfect centerline are achieved *only* with inflation.

Excellent topics for the panel discussion on X-ray would be:

1. A method to reference against the true centerline of the inflated tread area for automatic analysis of belt runout.

2. Degree of inaccuracies contributed by the mechanical portion of the manipulator and their end effect upon measurements required for gaging – electronic or visual.

In conclusion, I would like to say that, with continued close cooperation between the rubber industry and the industrial X-ray manufacturers, we should all experience tremendous improvements in tire quality control systems with X-rays.

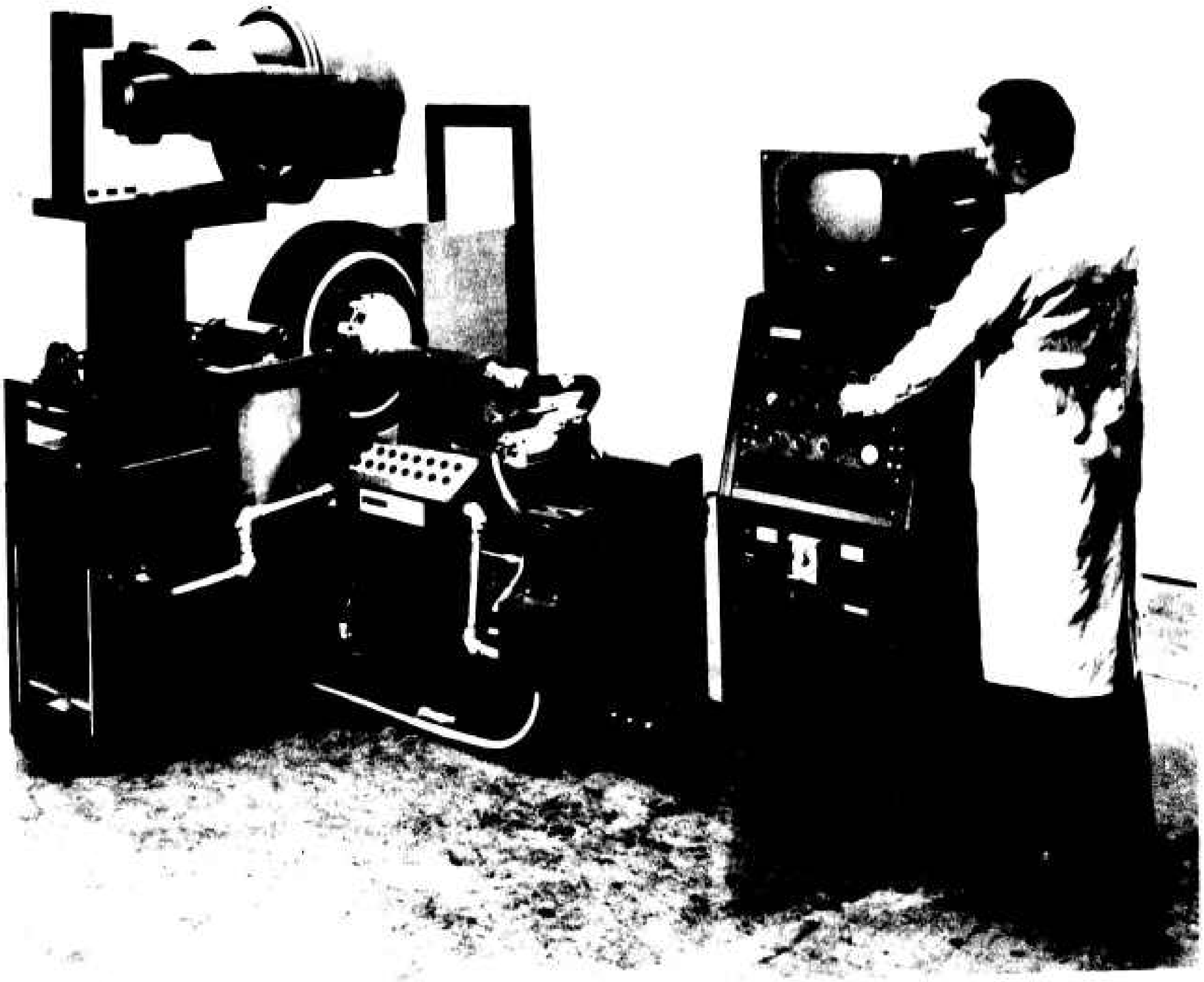

FIGURE 10

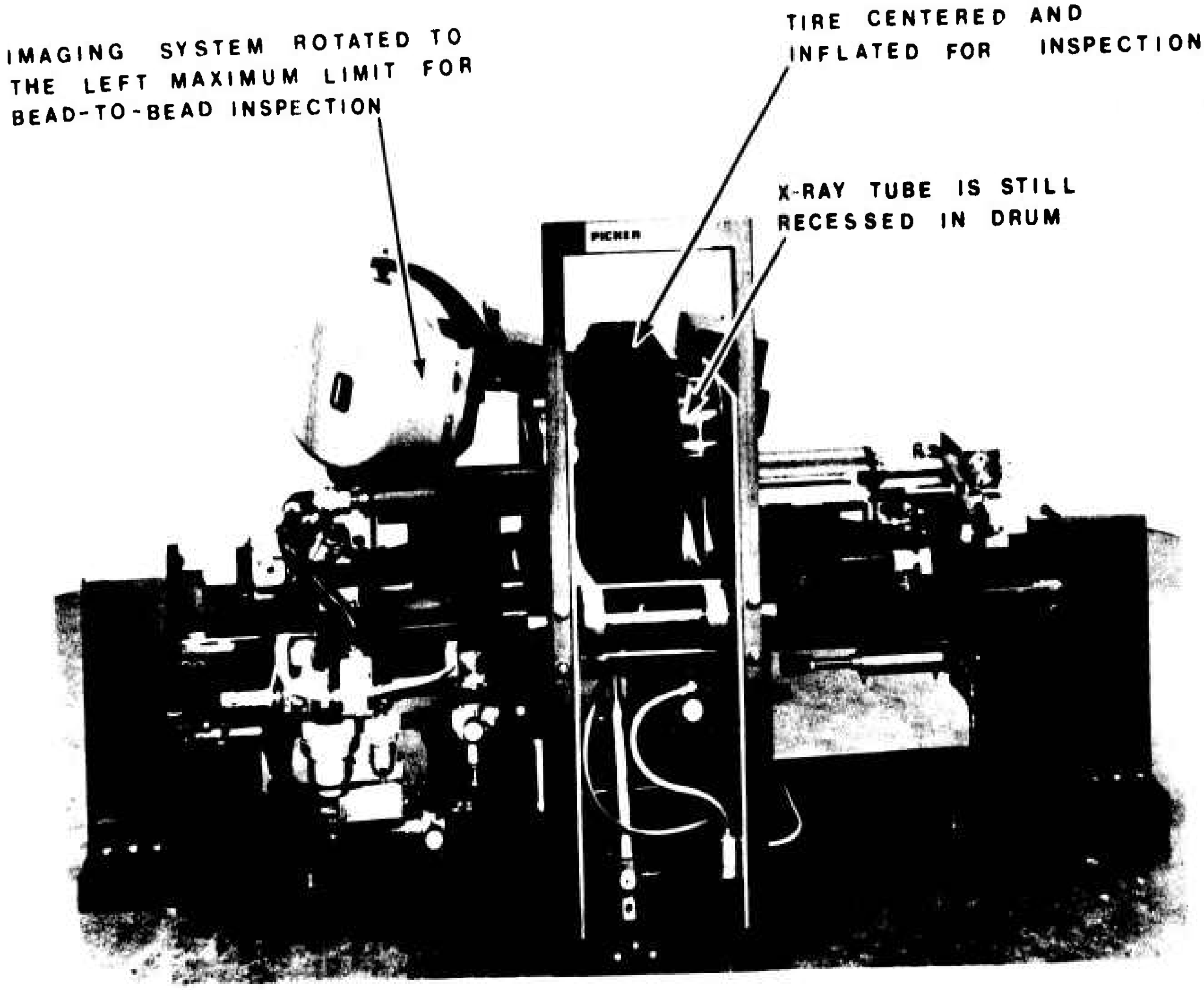
IMAGING SYSTEM ROTATED TO
THE LEFT MAXIMUM LIMIT FOR
BEAD-TO-BEAD INSPECTION
TIRE CENTERED AND
INFLATED FOR INSPECTION
X-RAY TUBE IS STILL
RECESSED IN DRUM
PICKER

FIGURE 11

XERORADIOGRAPHY: ITS APPLICATION TO TIRE INSPECTION

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ABSTRACT

Xeroradiography is an X-ray imaging system which uses the principle of Xerox copiers. The Xerox 125 System for xeroradiography is a completely new and automated system and consists of two units – a conditioner and processor. Xeroradiography is completely dry from start to finish and requires no darkroom, film or plumbing.

The conditioner prepares the plate for X-ray exposure by placing an electrostatic charge on the plate and loading it into a cassette ready for use. When exposed, X-rays interact with the xeroradiographic plate to form a latent electrostatic image. The processor develops the electrostatic image on the plate with an oppositely charged powder and then fuses the powdered image to paper. The total process takes under 2 min, excluding setup and exposure.

Its use in tire inspection will be illustrated with a number of slides showing actual case studies.

Techniques and applications are discussed.

Xeroradiography combines the xerographic process with X-ray exposures to produce permanent radiographic images. Although xeroradiography is widely applicable to both medical and industrial use, this review describes only one industrial application: tire inspection.

Because many papers have been published [1-3] on xeroradiography, the principles of the process will be reviewed only briefly here. Unlike silver halide films, xeroradiography is based on photoelectric and photoconductive phenomena – not photochemical. Its X-ray sensitive medium is a charged selenium photoconductor, called the photoreceptor or plate. After exposure, the latent X-ray image on the plate is developed with a cloud of charged powder. The xeroradiographic image is then permanently fused to special paper. This xeroradiograph (XR) can be examined immediately in ambient light.

The present xeroradiographic equipment (Xerox 125 System) (Figure 1) consists of two units: the *conditioner* (on the left) supplies a charged plate on demand; the *processor* (on the right) accepts the plate after X-ray exposure, develops the image, transfers and fuses the image to paper, and cleans the plate for reuse. Both units are automatic, and will produce a dry, archival quality image in less than 2 min, excluding the time for the X-ray exposure.

Radiographers generally refer to sensitivity as the size of the smallest detail which can be seen, or the ease with which images of small details can be detected. Contrast sensitivity is more specifically defined. It is the ratio of the minimum perceptible abrupt thickness to the total thickness of the object. Xeroradiography exhibits a unique form of local contrast sensitivity called edge enhancement. After exposure, fringing electrical fields exist in the latent image between areas of different charge levels. These fringing field lines result in more than average developer deposition along the edge of the charge discontinuity.

This edge enhancement effect gives xeroradiographic images excellent acutance and high detectability for small details. It is particularly advantageous to X-ray NDT techniques such as tire inspection, where it is necessary to image small or subtle changes in specimen density, while overall specimen X-ray density is low. Other NDT applications with similar requirements include light alloys, composite materials, ceramics, etc.

Exposure speed with xeroradiography is considerably faster than with Class II films at low kilovoltage but decreases as kilovoltage is increased. In the range below 150 kV, xeroradiographic exposure is about five to eight times faster than of Class II film. This, combined with xeroradiographic image enhancement from the edge effect and the apparent wide latitude of exposure, offers a very desirable imaging technique for tire inspection when high volume is not a requirement.

As part of its nondestructive tire inspection program, one company made a number of xeroradiographs of passenger, truck, aircraft and OTR tires. These photographic reproductions of xeroradiographs are representative of that inspection program. All of the passenger tires were exposed at 45 KVP, 25 MAS, 12 in. FST. The others were exposed at a range of kilovoltage from 120 KVP to 150 KVP, 60 MAS, 7 ft FST.

Figure 2 is a passenger tire tread and upper sidewall area showing the wire belt under the tread. The nonuniformity of the wire matrix can be seen at several points. At the upper sidewall in the center of the image, note the slight separation of the sidewall from the tire carcass. The tread design is also within the wire belt matrix.

Figure 3 shows a passenger tire with more detail in the area between the sidewall and the tread. This is referred to as the tire shoulder. The dots in the picture are vents in the mold to facilitate rubber flow during the vulcanization process. In the center of the image, there is a separation at the extreme edge of the tread in the upper shoulder.

Figure 4 demonstrates a passenger tire with a wire belt under the tread. The image shows the wire belt splice and spread wire cords in the splice area. The uniformity of the wire belt can be seen in the areas away from the splice.

Figure 5 detects trapped air and a slight separation in the sidewall of a passenger tire. The flared belt edge and paired wire cords can be seen in the top belt.

Figure 6 shows a passenger tire with trapped air and a separation in the upper sidewall.

Figure 7 reveals another passenger tire with trapped air and a blister in the shoulder. There is a slight displacement of the belt due to the blister.

Figure 8 detects foreign material in the tread rib of a passenger mud and snow tire. The white lines in the tread pattern are sipes, or kerfs, molded into the tread design to improve braking action on wet road surfaces. The alligator pattern on the sidewall is really on the inside of the tire, molded on the inner liner compound during vulcanization. A carcass-ply splice can be seen where the cords have been overlapped extending from the sidewall to the tread shoulder.

Figure 9 shows a truck tire upper sidewall with trapped air at the base of the lug. The alligator pattern, molded to the inner liner, and the mold vent pattern can be seen.

Figure 10 demonstrates an off-center belt condition in a radial truck tire. The belt is applied directly under the tread. At the edge of the belt on both sides, the edge of the tread lugs can be seen.

Figure 11 is an aircraft tire of approximately 30-ply rating, the type used on commercial aircraft such as the 747, DC-10, and the L-1001. There are no apparent defect in the image, which shows an area from the bead wires to the upper sidewall region. The ply endings are visible as the parallel lines. The ply turn-up height can be measured from the xeroradiograph. The radial lines extending from the bead to the upper sidewall are molded into the inner liner during vulcanization to eliminate trapped air.

Figure 12 is a similar tire to that shown in Figure 11. There are no apparent tire defects in this image, which shows the detail of the lower sidewall area. The mold vent pattern, details of the bead wire bundle, and concentricity can be seen. The bead wire ending with the step off from the various wire strands is normal.

Figure 13 demonstrates the tread area from a heavy duty retread tire. Note the contamination of the buffed tread surface with foreign material prior to application of the retread rubber. The white lines are tread grooves, and the dark series of parallel lines are molded into the inner liner during new tire vulcanization.

Xerox is looking to the tire industry to further define uses as well as limitations of present xeroradiographic equipment for NDT of tires. As requirements for X-ray inspection in general and xeroradiography in particular are better defined, Xerox will review and redesign its equipment to meet these needs.

FIGURE 1

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1. McMaster, R. C. and Hoyt, H. L., "Xeroradiography in the 1970's", *Materials Evaluation*, 265-274, December 1971 (38 references cited).
2. McMaster, R. C. (Editor), *Nondestructive Testing Handbook*, Vol I, Ch 22, The Ronald Press Co., 1973 (13 references cited).
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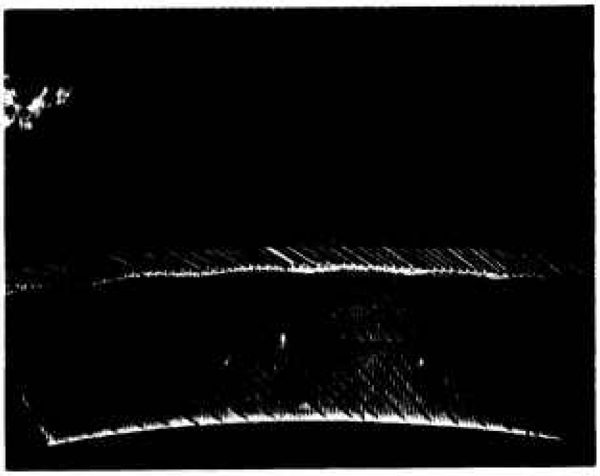

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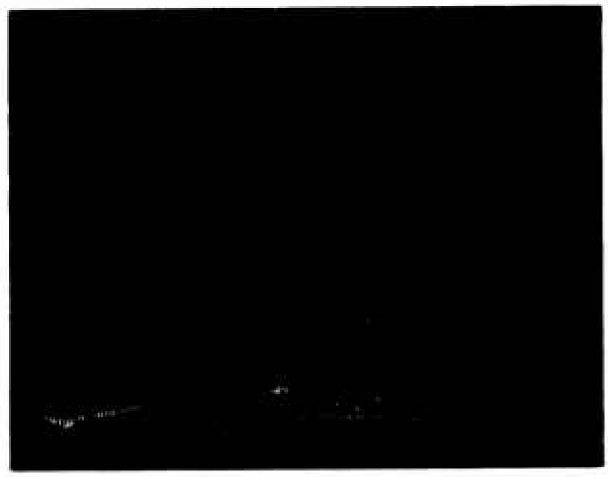

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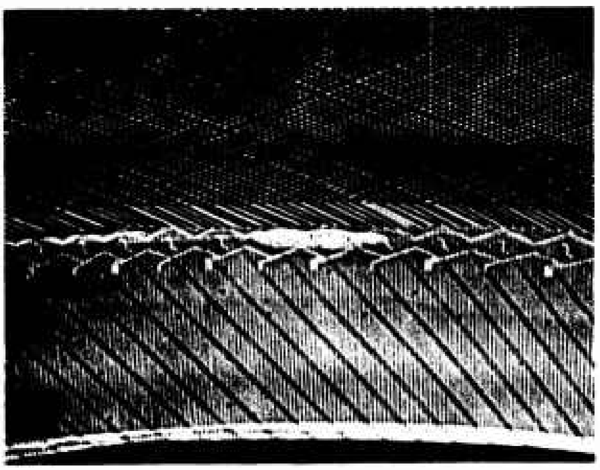

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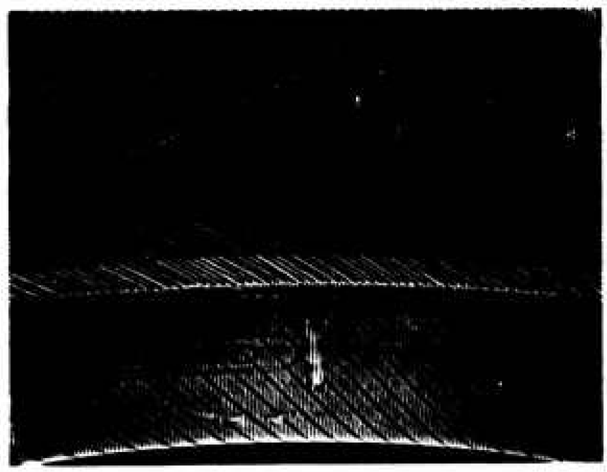

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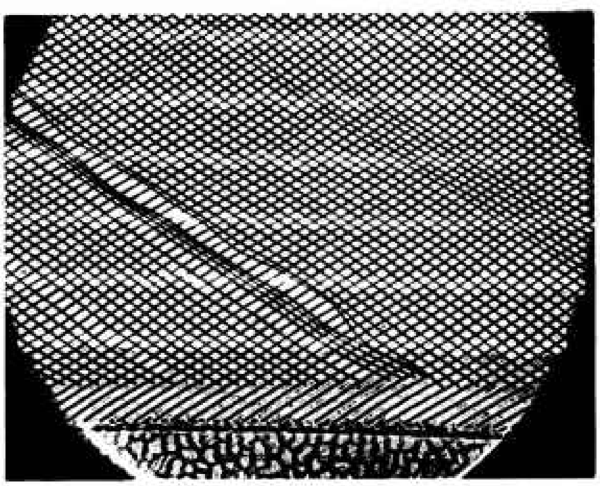

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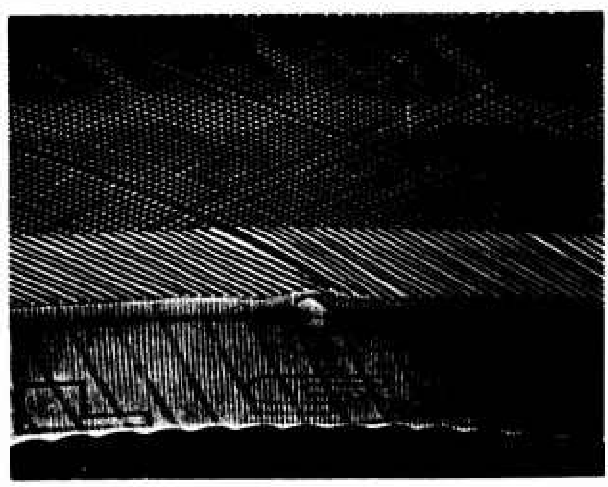

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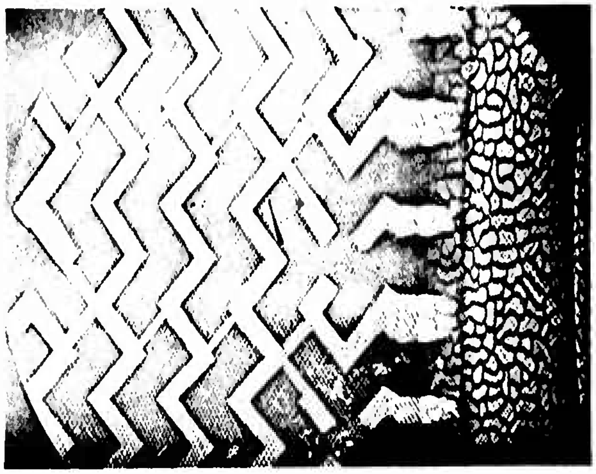

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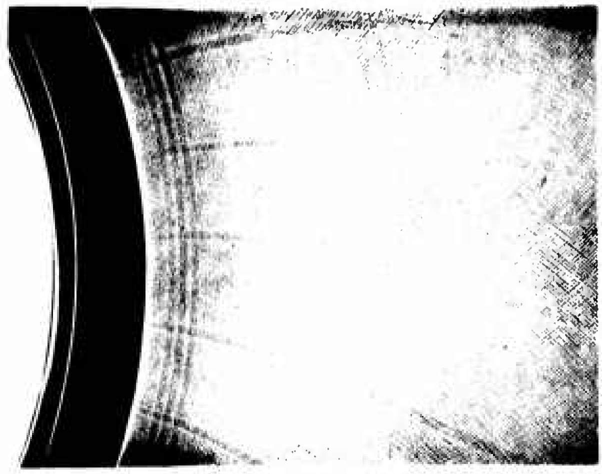

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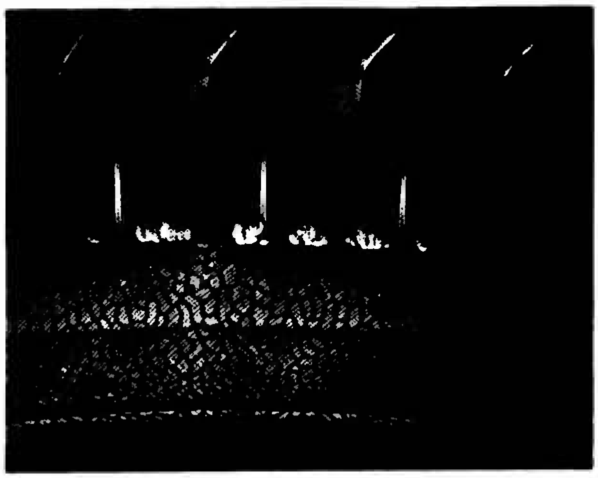

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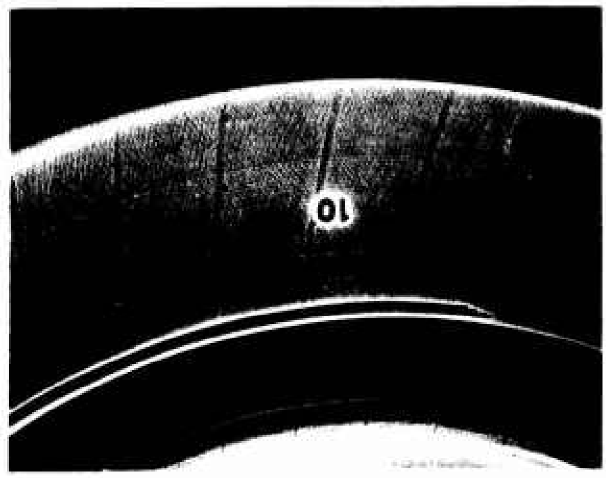

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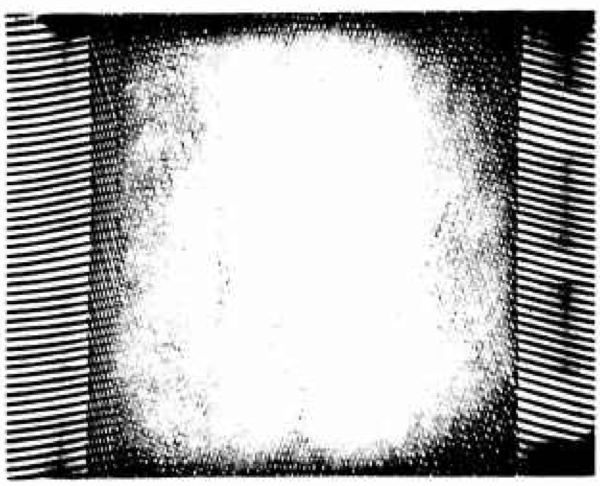

FIGURE 10

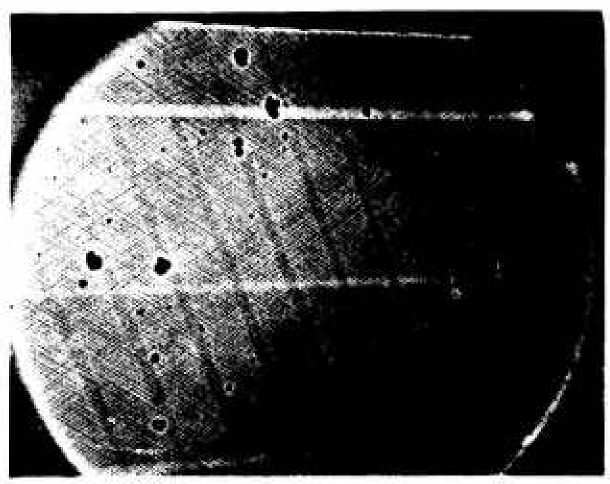

FIGURE 13

TIRE INSPECTION WITH KODAK INDUSTREX INSTANT 600 PAPER

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ABSTRACT

In the field of nondestructive testing, industrial radiography is a mature and leading inspection method. A brief description tion of industrial radiography and its application is given. The nondestructive testing market is segmented, and each industry imposes different demands on the industrial radiographic method. These demands result in a great variety of techniques with varying energy ranges, exposure times, processing conditions, and, last but not least, sensitivity requirements.

Paper radiography, as a complement to film radiography, is an important part of the effort to provide the industry with a range of image quality at commensurate prices. Because of the interest expressed by the tire industry, this paper discuss the characteristics of the Kodak INDUSTREX Instant 600 Paper products line.

As part of the discussion comparisons will be made with present radiographic methods using film. Major topics discussed are: use of reflection versus transmission images, Kodak INDUSTREX Instant 600 Paper, stabilization processing, image quality, and economic factors.

What is nondestructive testing? An examination of any defect in any manner which will not impair its future effectiveness. Only through NDT can random discontinuities be found which will contribute to the prevention of operational failure.

Specifically, here's what NDT does for you:

1. Reduces materials and production costs
2. Prevents wasted labor and machine time
3. Determines product quality
4. Becomes a necessity in view of increased manufacturer's product liability.

Promotional and advertising benefits can be significant. More than one manufacturer has increased customer acceptance and company growth through product reliability.

What is a radiograph? A radiograph is a photographic record produced by the passage of X-rays or gamma rays through an object onto a film. Radiography today is one of the most important, most versatile of all the NDT methods used by modern industry. Employing highly penetrating radiation which does not damage the part itself, radiography provides a visible record of internal conditions containing the basic information by which product soundness can be determined. Radiography, the first of the modern methods of nondestructive testing, has led hundreds of industries to put great confidence in the information it supplies. The list is growing year after year in industries' management, designers, engineers, and production personnel. The results are sound practices, dependable products, and high yields.

A NEW IMAGING METHOD FOR INDUSTRIAL RADIOGRAPHY

Since the discovery of X-rays about 76 years ago, industrial radiography has become a mature NDT discipline. Innovations which occur with some frequency in new "emerging methods" happen so infrequently in a mature method that, when they do appear, they have the flavor of a "breakthrough."

A new completely balanced imaging method for industrial radiography has been introduced by Eastman Kodak Company to the profession. This new procedure is unique, unusual, and promises to be a significant innovation in industrial radiographic technology, particularly in the area of cost reduction of radiography, speed of radiographic examinations, and the convenience of operation. The method based on the use of INDUSTREX Instant 600 Paper has four components: a special sensitized paper, two types of intensifying screens, a processor, and two chemicals for the processor (Figure 1).

First, however, it is necessary to give a brief introduction to stabilization processing because this process constitutes an important part of the technique. Stabilization processing is a method of producing an immediate but nonpermanent photographic image. The stabilization process has evolved over many years and has had many advantages for the phototypesetting industry. This process is now being introduced in the field of industrial radiography.

The quest for simpler, more rapid processing of photographic papers began years ago when photographers developed, fixed, and used short washes to produce prints with short-term stability. Such prints were suitable for immediate purposes, but they lacked the long-term permanence associated with conventional processing.

Processes to produce short-term stability without washing were studied quite extensively in the late 1940's, and at that time the various processes were labeled "stabilization processes" -- rapid processing without washing. In the mid-1950's, rapid processing was introduced using elevated temperatures for the development and stabilization. In the mid-1960's, products were introduced which incorporated the developing agent in the photographic paper and avoided the need for high temperature processing.

The principal advantages of the stabilization method were the rapidity of processing, simplicity, and low cost. The processor required little darkroom space and no direct water or drain connections. The processing speed was in the order of 6 ft/min. The stabilization process is relatively insensitive to temperature, operating satisfactorily over a range of 65° to 85°F, with only small speed shifts and no noticeable contrast or density changes. Users rarely worried about processing conditions.

This simplicity and speed of the stabilization process was recognized as a means of providing a paper radiographic method – complementary to film radiography and satisfying consumer demands for quality – part of Eastman Kodak Company's effort to provide industry with a range of image quality at commensurate prices. The result was the introduction of Kodak INDUSTREX Instant 600 Paper.

The INDUSTREX Instant 600 Paper is uniquely different from the ordinary photographic papers you may be familiar with. This paper is coated with a silver halide emulsion which also incorporates developing agents in its emulsion (Figure 2).

The INDUSTREX 600 Paper is exposed as conventional X-ray films either directly, with lead screens, or with the new Kodak INDUSTREX Intensifying Screens, F-1 and F-2, application and results desired by the quality control department being the deciding factor as to which technique to use.

It is the combination of the 600 Ppaer with one of two new INDUSTREX Intensifying Screens that adds new dimension to NDT testing. The screens shown in Figure 3 are the F-1 and the F-2. Both of these screens are new to industrial radiography and produce energy in the ultraviolet range which closely matches the wavelength energy response of the INDUSTREX Instant 600 Paper.

Figure 4 is a typical example of the data that can be developed for a particular industry. The data were provided by foundries using INDUSTREX 600 Paper. The combination of this paper with the E-1 Screen gives a speed six times that of INDUSTREX AA Film used with lead screens at

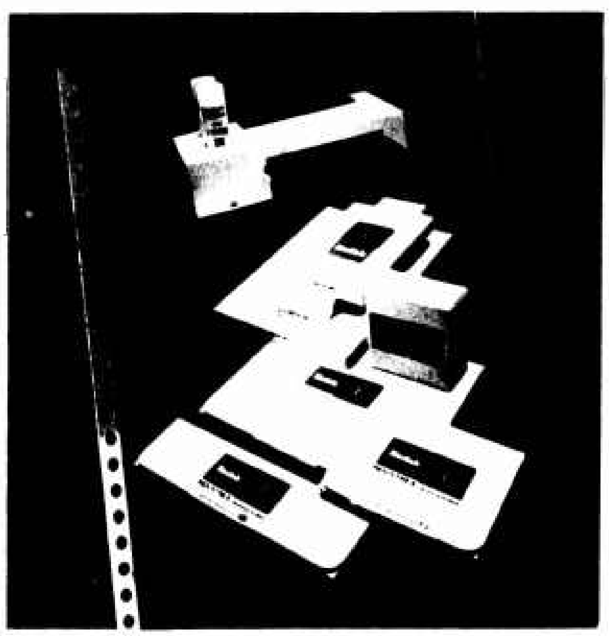

FIGURE 1

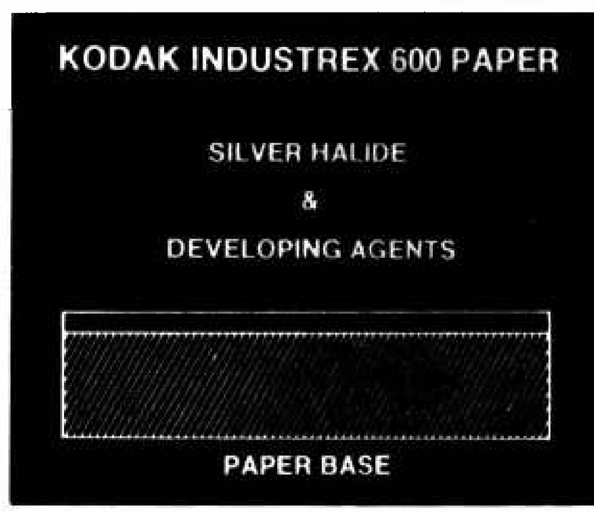

FIGURE 2

200 kV through 1/2 in. of steel. The resulting paper radiograph has high contrast and short latitude.

When an F-2 Screen (Figure 5) is combined with the 600 Paper, we get a speed 1-1/2 times that of INDUSTREX AA Film with lead screens at 200 kV, and 1/2 in. of steel. The resulting radiograph has lower contrast and a longer latitude and provides greater detail.

The INDUSTREX Instant 600 Paper can be used in a cassette or in cardboard, vacuum, or plastic holders. Select the screen type you want to use and place it in the holder screen side up (Figure 6). Only one INDUSTREX screen is needed. Place a sheet of INDUSTREX 600 Paper on the screen, emulsion down. Close the cassette or holder. Expose with the INDUSTREX screen between the tube and the paper. If a technique requires lead screens, they may also be placed in the holder in the appropriate places. As in all radiography, good screen-paper contact is essential to obtaining high detail. For very critical radiography, such as circuit boards, the use of a cassette or vacuum holder is particularly recommended to obtain the maximum screen-paper contact.

Recent applications, such as those found in the tire industry, indicate the value of direct exposures. Such a configuration is available in Ready Pack form (Figure 7).

Exposure of the paper is done as with the exposure of X-ray film. In Figure 8 we see a radiographer placing the cardboard holder, containing the paper and screen, beneath a magnesium casting. Experience has shown that most common sources of X or gamma radiation may be used.

Most of the investigational radiography using paper has been done between 20 and 300 kV. Some has been done with iridium 192 and cobalt 60 with considerable success. Super voltages and X-rays above 1 MEV have been investigated and preliminary results look promising.

An industrial radiograph is usually measured by its penetrameter sensitivity. This is a standard test piece commonly included in every radiograph as a check on the adequacy of the radiograph. The test piece is commonly referred to as a penetrameter in North America and an image quality indicator (IQI) in Europe. The penetrameter of IQI is made of the same material as the specimen being radiographed and contains structures (holes, wires, etc.) the dimensions of which bear some numerical relationship to the thickness of the part being tested. As with standard X-ray film systems, the INDUSTREX 600 Paper system depends upon how carefully the exposure is made, the choice of intensifying screens, the kilovoltage selected, and control of scattered radiation. When trade tests were first undertaken, it was anticipated that a radiographic sensitivity of around 2-2T could be expected. However, in practice, some surprising sensitivities

FIGURE 3

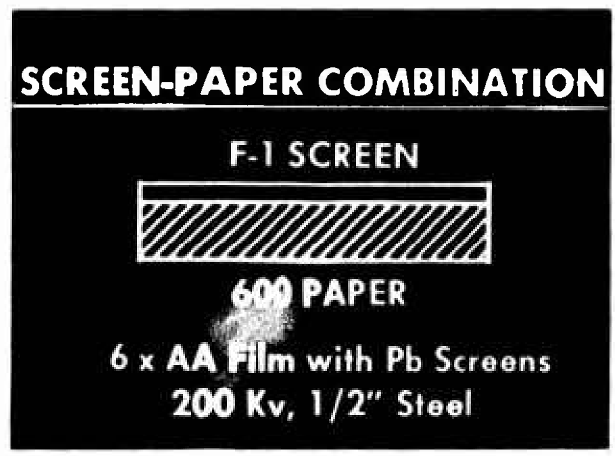

FIGURE 4

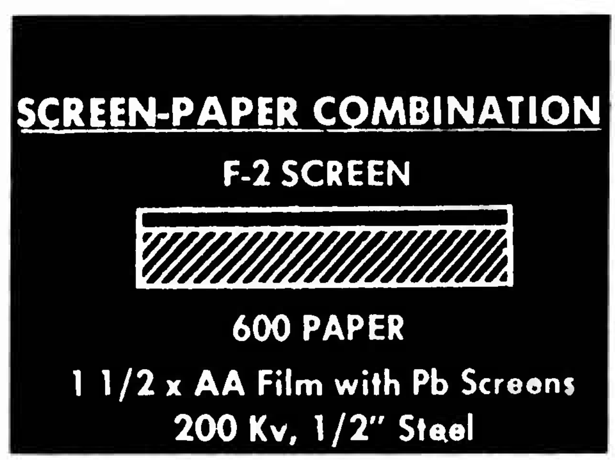

FIGURE 5

FIGURE 6

were actually realized. With a reasonable amount of care, 2-1T penetrameter sensitivity can be obtained in many cases of radiography between 20 and 300 kV. In radiography of electronic components and circuit boards, a different penetrameter is used and the 1 mil wires were easily visible. Those that have used iridium 192 and cobalt 60 to make radiographs report showing acceptable sensitivity in a number of cases.

In film radiography, density is viewed by transmitted light. In paper radiography, density is viewed by reflected light. The proper reflection densities for paper are significantly lower than those for film. This inexpensive, easy-to-use, reflection density guide is available for checking paper densities. This will be a great help in determining exposures.

After making the trial exposure, the radiograph is processed and its density checked with a Kodak Reflection Density Guide (Figure 9). Experience indicates that the ideal reflection density is about 0.70 in the area of interest, with an acceptable range of densities between 0.20 and 1.3. It is difficult to give precise recommendations because the selected density almost always depends on the subject radiographed and the customer's preference.

Experience also indicates that the kilovoltage can usually be reduced with adequate penetration of the subject, thereby giving a significant increase in subject contrast.

In some cases, the F-1 Screen and 600 Paper combination may be so fast that it cannot be handled by the X-ray timer. In this case you can switch to an F-2 Screen and 600 Paper combination which will require four times more exposure and probably can be handled by your X-ray timer. If further increase in exposure time is required, one could use lead screens or no screens at all.

After exposure, the paper must be stabilization processed. Now that we are all experts on the stabilization process, let us apply our expertise to the INDUSTREX 600 Paper method. You may recall that stabilization processing is a machine operation producing black-and-white prints much faster than is possible by conventional develop-stop-fix-wash processing. For example, exposed INDUSTREX Instant 600 Paper processed by stabilization, makes quality ready-to-use radiographs in seconds. These stabilized prints are not permanent because the chemical reactions within the emulsion have been stopped only temporarily. They will, however, last from 6 to 10 weeks, which is long enough to serve a number of purposes.

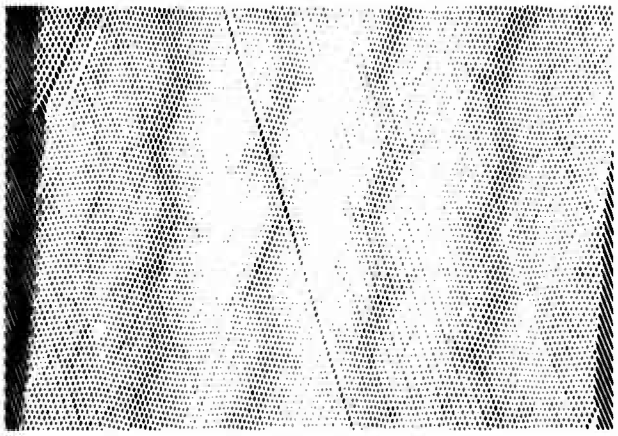

FIGURE 7

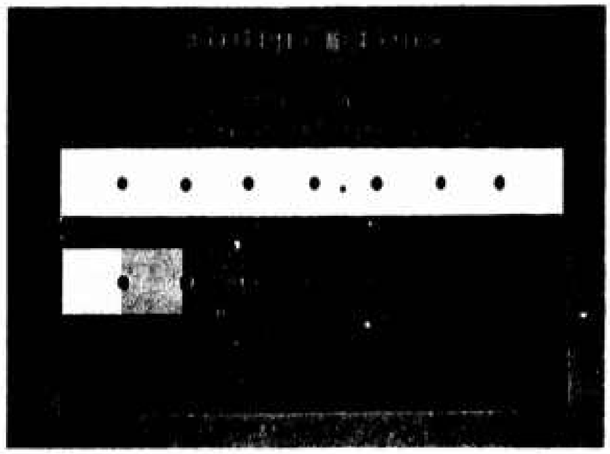

FIGURE 9

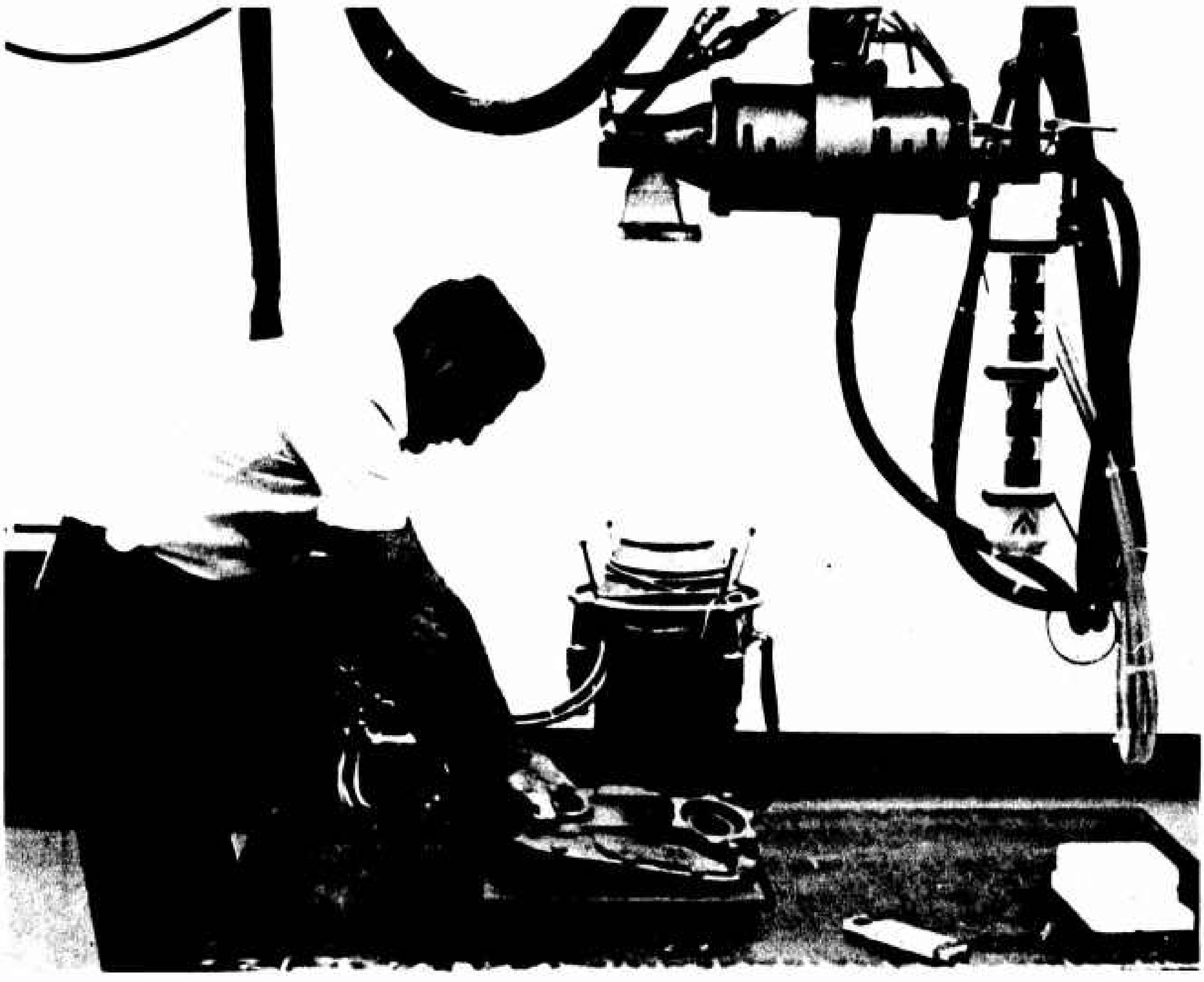

FIGURE 8

In papers designed for stabilization processing, developing agents are incorporated in the emulsion. Development is achieved by applying an alkaline activator to the emulsion surface. The stabilizer is then applied to neutralize the activator and to convert any remaining silver halide to relatively stable, colorless compounds.

To accomplish processing, we have a very compact, portable, bench-top automatic processor called the Kodak INDUSTREX Instant Processor, Model P-1 (Figure 10). This processor weighs about 40 lb and requires only 110 volt house current to operate. Since water is not required to process these radiographs on paper, no plumbing is necessary nor, for that matter, a sophisticated darkroom. A simple light-tight closet will do. This neat little processor, costing less than $600, will produce "damp-dry" radiographs in 10 sec.

The chemicals used to process the paper radiograph are different, too. Since the emulsion of the INDUSTREX Instant 600 Paper contains its own developer, it needs another chemical – INDUSTREX Instant Activator – to release its developing power to the exposed silver bromide crystals. Instead of fixing the image in the normal manner, INDUSTREX Instant Stabilizer chemically locks up the unexposed silver halide but does not remove it. Both the INDUSTREX Instant Activator and INDUSTREX Instant Stabilizer come in a convenient 1-qt bottle. A "chicken feeder" type replenishment device keeps the level of the solutions in the processor constant. These bottles are simply "plugged into" the processor as seen in Figure 11. They are sufficient to process 150 sq ft of paper, about a hundred 14 by 17 in. radiographs.

The processor, being automatic, requires that the paper be started into its roller system. Figure 12 shows how a paper radiograph is fitted into the processor, emulsion side down. Since the processed radiograph comes out the back of the processor in only 10 sec, the operator usually has his hand ready to receive the processed radiograph. The radiograph is damp-dry at this point and is ready to read. It usually air dries in 2 or 3 min under normal conditions of relative humidity.

The radiographic image presented on the paper looks like a standard film radiograph (Figure 13). Under normal storage conditions, it will last from 6 to 10 weeks. If a more permanent image is desired, commercial quality lasting at least 7 yr can be obtained by fixing, washing, and drying using conventional hand processing tanks and trays, at any time within the 6 to 10 week period. Having the image on paper is an advantage since it is viewed by reflected light and does not require expensive X-ray illuminators.

Hand processing of film requires approximately 1 hr. The standard processing time using an automatic industrial film processor is 11 min. Some of these processors have been modified to produce processed radiographs in 8 min. The fastest possible processing of industrial X-ray film in automatic processors is 4-1/2 min. The fastest processing of medical X-ray films is 90 sec. All of this is compared with 10 sec access time of the INDUSTREX Instant Processor.

What about costs? The cost of the INDUSTREX Instant 600 Paper in a size of 14 by 17 in., completely exposed and processed, is between one-third and one-fourth the cost of comparable film radiography. The cost of the paper alone is closer to one-fourth the cost of the X-ray film alone. The cost of the INDUSTREX Instant Processor is less than $600 compared with around $16,000 for one of the leading automatic film processors. This is actually only 3.7 percent of the cost of the film processor.

INDUSTREX Instant Paper has several unique aspects. The first of these is shorter exposure time. The speed of the paper-screen combination, as well as contrast, will be dependent on screen choice, kilovoltage, and absorbing materials. Average processing time for sheets is 10 sec, depending on paper size. It can be interpreted immediately by reflection viewing. Image stability will be 6 to 10 weeks. If permanence is desired, the radiograph can be fixed, washed, and dried at any time during this period.

The small size and 40-lb weight of the processor allows it to be used in the field and at on-site locations in the plant, especially when using a light-tight box built around the feed tray. It does not require water for processing, and it does not need a rigid temperature control system. It can operate in a temperature range of 65° to 75° F. The processor is extremely simple in operation, maintenance, and repair.

Under average conditions, the radiographic quality obtained is approximately 2 percent. We have had incidents where, with fine tuning, we were able to obtain close to 1 percent sensitivity (aluminum objects). In general, however, this method will appeal mainly to those applications which require radiographic sensitivity up to 2 percent and where a long-term image stability is not important.

Trade tests have been conducted on a variety of materials: tires, electronic circuit boards, paintings, wood, graphite composite materials, castings of steel, aluminum, and magnesium, steel wells including pipelines, packaged foods, titanium chips, etc. The INDUSTREX 600 Paper and equipment have proven their feasibility in the various industries.

All of us know that NDT is becoming an inherent part of the manufacturing process. You have to decide what role radiography will play in your NDT operation, and you

have to decide the flexibility of your radiographic system, the capital expenditures allowed, the quality level needed, and the usefulness of a visible record.

Based on the work done by the various manufacturers, it is our impression that Instant 600 Paper can provide you with the needed quality and flexibility at an acceptable price.

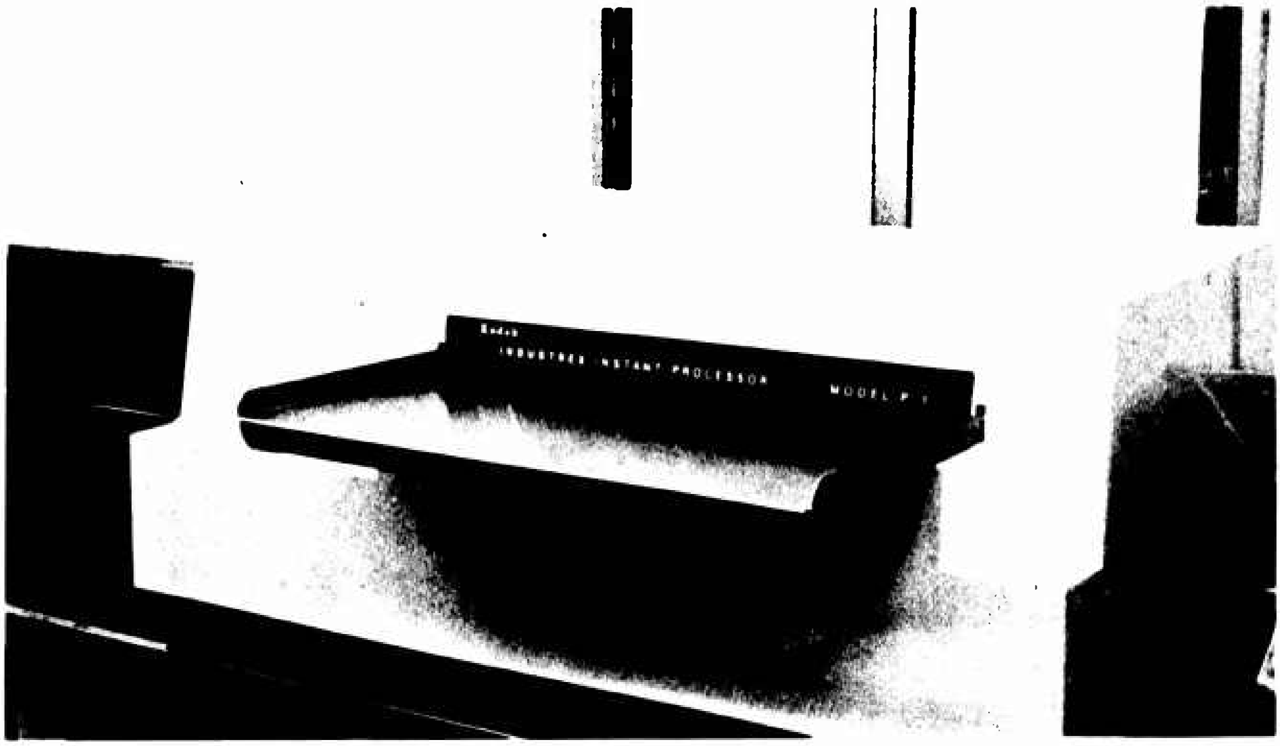

FIGURE 10

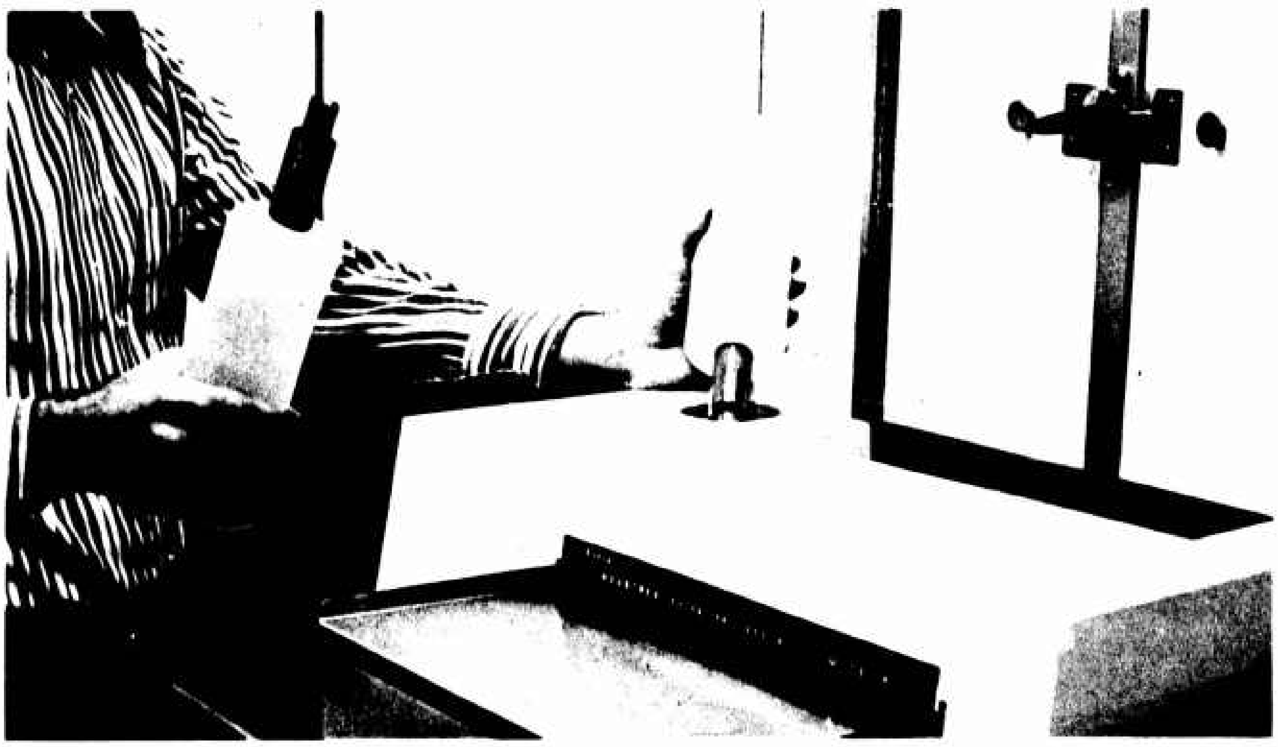

FIGURE 11

FIGURE 12

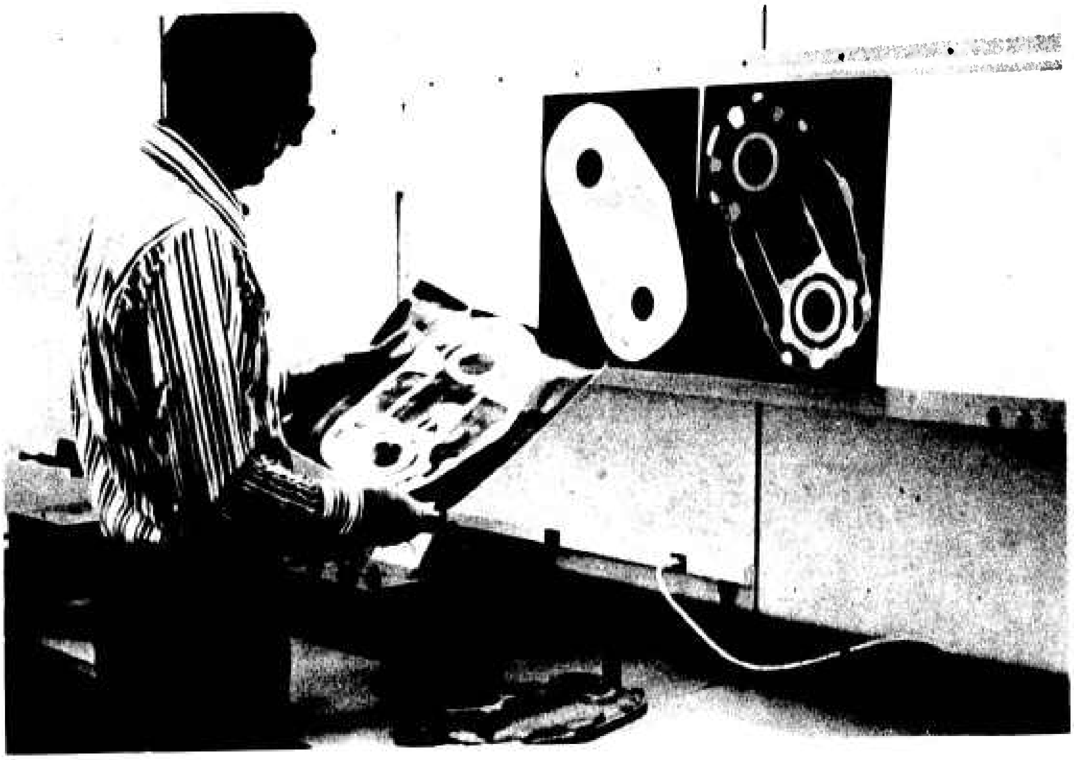

FIGURE 13

CHAPTER VII – WORKING GROUP REPORTS

INTRODUCTION

Charles P. Merhib, Moderator
Army Materials and Mechanics Research Center
Watertown, Massachusetts

The chairmen of the groups are: Holography, Dr. Ralph M. Grant; X-Ray, Robert C. Fiorille; Infrared, Dr. I. W. Ginsberg; Ultrasonics, Gwynn K. McConnell. Each chairman will give a summary of the group's session. After the group reports, we will have a panel discussion and panel members will answer questions from the audience.

HOLOGRAPHY

Dr. Ralph M. Grant
Oakland University
Rochester, Michigan

The holographic committee met and consisted of 10 people. We had an excellent session in that almost every individual who attended contributed very heavily, each one speaking for an average of about 10 min whether he had had past holographic experience or not; those who had not related to those specific things they felt were needed.

Much of the discussion in our group centered around the meaning of defects in tires. Mr. John Morgan of Mohawk Rubber pointed out that, even though he had not been associated with the field, he would like to see a great deal more detail on the meaningfulness of the various anomalies or defects in tires. Mr. Melvin Salmon, Hill Air Force Base, with his experience in aircraft tires, was able to provide an immense amount of very meaningful and practical data to us. Fred Goodrum and John Peters of GSA in Boston have not had experience with holography in the past, but they, as well as Mr. Morgan, would like to see more data. Dave Yoshida of Palo Alto also had not had experience in the holographic field before, and similarly made excellent comments on things that he would like to learn via holography.

Mike Cannazzaro of General Motors was a very important member of our team, since General Motors has probably individually tested more tires, aside from myself, than anyone else. As a matter of fact, I think between Harry Ceccon of DOT, Mike Cannazzaro and myself we have tested a little over 5,000 tires. I think that's over half of all the tires that have been holographically tested to date. Mike is going to present a paper to our American Society of Nondestructive Testing–Holographic Committee in October, and I will send a notice to each one of you on the Holographic Nondestructive Testing Session. He mentioned that he is presently gathering data for his paper titled *Holographic Nondestructive Testing of Pneumatic Tires Carried Out at the G.M. Proving Grounds.*

Firestone has been one of the other contributors in holographic research and has been involved, off and on, in that area for the past three to four years. Gerald Potts of Firestone described some of his excellent work on the vibration analysis of tires by holography and made some comments upon testing in general. He will also present a paper in October titled *A Study of the Vibrational Analysis of Tires by Holographic Interferometry.*

Durk Pearson of TRW described his company's interest in holographic nondestructive testing. They have been doing work on pulse holography and hope sometime in the future to have some equipment available for the possibility of detecting separations in tires which are mounted on the vehicle.

In summary, the group in the holographic nondestructive testing field felt that they would like to see a great deal more data from other members of the nondestructive testing community – the ultrasonics, infrared, and the X-ray people – so that this data can be compared and something can be done to establish greater meaningfulness in the data that we are reading. A few people seem to be gathering most of the data.

Well, gentlemen, the holographic tire testing people have been doing the work, and we'd really like to see the other committees gather some data for comparison. Hopefully, a year from now we could have another session in which a great deal of data comparison and discussion could take place.

X-RAY

Robert C. Fiorille
Picker Corporation*
Cleveland, Ohio

We had 17 people in attendance at the X-Ray Inspection in Tires workshop, and they represented 13 different companies and/or agencies. The discussion covered five or six major topics, and it was learned that almost every tire manufacturer, that is, every original equipment manufacturer, uses X-ray inspection of some form.

The general feeling of this group was that a lot of meaningful information was exchanged at this seminar, and that any time less than one year from today would be too soon to have another meeting. Everyone favored a repeat, but in the next session they would like a wider representation of manufacturers and users of X-ray equipment and manufacturers of other than passenger car tires (aircraft and retreaders).

Tire manufacturers, like many of us, have some differences in opinion of how they might apply this equipment or what they would like to see in the nature of the machine designs. In general, they all agree that X-ray inspection has a very definite place in the tire industry, and this means both radiographic and fluoroscopic techniques, as well as the very recent innovative uses of paper radiography. Someone extended appreciation for the response that the manufacturers of X-ray inspection equipment have had to the needs of the tire industry. There was recognition of the fact that there have been rather significant developments in this state of the art, particularly within the last three or four years.

Of course, X-ray inspection has been in use for many years. The discussion was more related to how the tire manufacturers are employing this NDT process. One of the primary areas is to help in the elimination of what we can call the nonconformance tire. It also was interesting to learn that it is used very heavily in the development and design stages for new product lines. Here, X-ray inspection is used to determine what changes happen to the material placement in the building or the curing processes. Another area for the use of X-ray inspection by many of the companies is as a job-training tool. The tire builders themselves are invited to come in and view some of the X-ray images and learn from these what possible corrections they can employ in the buildup of the tires.

Another subject of discussion was the reawakening of interest in inspecting tires in the green stage. Some companies now are going back to the thought that X-ray inspection might be still more useful if they applied it to the green as well as the cured stage. They feel there could be a substantial cost saving factor involved if they were able to determine poor building construction on a fair percentage of the green tires before curing. An estimate of something like 40 percent of the total investment could be realized as a savings with this evaluation. That seems to be very significant and worthwhile to pursue, and certainly something that the tire inspection systems manufacturing concerns will look at very definitely.

Then, we went to a problem which is becoming more and more apparent to us, the development of a capability in inspection of some of the tire characteristics by a nonhuman element. One of the major points of concern is the difference of opinion that seems to exist among the tire manufacturers as to what part of the tire or point we will use as a reference.

One recently introduced X-ray system has a rim-mounted, tire-inflated, handling capability where the bead support point is the reference. Some at the workshop felt this was good, and others felt this reference was not absolute. So, there apparently is more discussion needed in this area, and quickly.

There is a problem characteristic not only to X-ray inspection but to all NDT techniques, and that is operator fatigue. An operator's efficiency may reduce significantly over a period of time, so many users of X-ray inspection employ a team

*Mr. Fiorille was with Picker at the time of the symposium but is now with Imagex, Inc., Mentor, Ohio.

program. The viewing operator is rotated with the equipment loading operator or tire programmer, and in this manner a more level efficiency is maintained.

Aside from understood design improvements necessary to simplify the operation of the equipment and lower the cost, the imaging capability in X-ray inspection was discussed. The trends that run in the manufacture of tires, i.e., multi-ply bias-cord, bias-belted fabric, bias-belted glass, bias-belted steel, radial all steel, have hard pressed the imaging performance of X-ray equipment. It is an area of constant concern and development, but, when you consider the speed and efficiency available with the bright image fluoroscopic system, there is a fairly equal trade off to the resolvability of detail.

The workshop touched lightly on the matter of accumulating data more meaningful to determining how effective all non-destructive testing is to the rubber industry. X-ray inspection, having been in use for more than 10 years, now seems to bear out as one of the more useful testing devices; hopefully, it will continue to be.

To the test equipment manufacturers, this meeting is very purposeful, and we look forward to the next with anticipation of learning more and getting a wider viewpoint by including aircraft and retread tire manufacturers.

INFRARED

Dr. I. W. Ginsberg
Sensors, Inc.
Ann Arbor, Michigan

Good morning, gentlemen. First, I want to thank Mr. Vogel for inviting me to the meeting. I have to say that this is the first meeting of this sort at which I've had an opportunity to give a paper on infrared for the tire industry.

As regards the working session in the Infrared group, it was a small group and the results of the meeting were similar to what Dr. Grant mentioned, that people have requested more information on how infrared or temperature measures tire performance.

However, with that, I would like to digress for a moment and give you some personal feelings as to my impression of NDT for the tire industry; I wish you would take these as strictly my comments, as you may not like some of them, and I don't want them to reflect on the company for which I work. After our short meeting, I was walking down the hall trying to decide which of the two meetings I would attend, the Holography or the X-ray session. I didn't attend the Holography session because I had done some work in laser coherence and felt that they weren't going to discuss the technical parts. I was really more interested in the X-ray session because so many people were taking an active interest in that area; also, I wanted to see what an accepted NDT tool was like for the tire industry. My first impression, after sitting in the session for a while, was that here is a situation where it seemed the discussion was related to how many angels could dance on the head of a pin. First of all, everybody knows that X-ray is a measure of the structure of the tire and that gross imperfections in structure do degrade tire performance. But what about small scale differences? If two of the plies are off by a fraction of a degree, how much does that cut down on tire performance? Does that change it by 10 percent in a lifetime? Does that give you a failure after 300 mi on the road? Exactly what does it mean? Well, the impression I got was that no one has really done a careful study as to the correlation between the structure of a tire and its performance except in the grossest sense. Yet nobody has raised a serious objection to this. People spend hundreds of thousands of dollars on X-ray test equipment, as they should, because structure is an important tire characteristic. But when the other NDT users or instrument suppliers come around and try to get you to buy equipment, the first question always raised is, "Well, that's great. I know that's very important; I know anomalies that you see with holography, thermal anomalies that you see with infrared, ultrasonic anomalies, are really there; but what do they have to do with tire performance?" My answer is, "I don't know."

Let's take a look at infrared for a moment. Everyone here will agree that temperature is an important parameter. I know it is; having looked at hundreds of tire failures, I have never ever seen a tire fail that first had not shown a hot spike or a thermal anomaly at the failure point – ever. Yet people say, "Well, let's correlate temperature data with tire performance or failure rates." It has been correlated with failure rates, and no other method has been so correlated with failure. But as for tire performance, I can't do the correlation with tire performance. Only you can do it. You know more about the tire performance characteristics, what defines tire performance, and that is really the job of the people making the tires and using them. Besides that, most suppliers can't afford to do it. Correlation is basically a statistical technique. You must have many tires of similar quality in order to get good correlation. Furthermore, what are you going to correlate it against? Right now you have, in-house, 80 to 90 percent of the equipment required to do thermal measurements, and that's a test wheel or a vehicle. So the cost is minimal. At the same time, in the other areas of NDT, you are also the ones, the only ones that can do a meaningful correlation between what defects mean and how they relate to tire performance. So as a personal feeling, what I would like to see at the next meetings of this sort are papers from the actual manufacturers and users of the equipment showing how these parameters relate to tire performance.

Whenever a manufacturer or distributor of NDT equipment gets up and tells you how the information relates to the various parameters of an object, it always comes out as a sales talk, and because of that it loses a lot of its effect. When the people who use the equipment can get up and give that sort of information, it carries a lot more weight in the tire community, as well as in the equipment community.

ULTRASONICS

Gwynn K. McConnell
Naval Air Development Center
Warminster, Pennsylvania

The Ultrasonic working group had a 3 hr meeting. We had 18 tire and nondestructive inspection specialists attending that meeting. The session was effective in that it permitted a good exchange of a lot of detailed information we didn't have the time to get across here at the general meeting, and it pointed out several gray areas, areas that are a problem to the application of NDT to tires. In particular, they are gray areas that are common to the application of nondestructive testing in general, and we in that field deal with them all the time, so we don't treat them as if they were not solvable or handleable. These are: what do we want to detect, what is a good reference standard, and what is a critical flaw. The ultimate information, the correlation of acoustical variations with tire performance, will only be generated by a large sample study. The utility of a test method may depend on the area of application. New automotive tires or rebuilt aircraft tires may not respond equally to a nondestructive test method. The tire industry representatives have emphasized that we tend to exaggerate the criticality of separations in automotive tires. However, acoustical techniques have demonstrated the ability to reveal subtle tire variations or gross delaminations, and now we must establish the relation to performance. The Navy inspection requirement for rebuilt high speed/high performance aircraft tires is intended to detect anomalies which may be considered gross compared to anomalies which characterize new automotive tires.

The working group recommends that much more work must be performed in each area of intended application of nondestructive testing. Natural flaw propagation and criticality information must be developed.

The most common defect in rebuilt aircraft tires is a carcass ply separation. The criticality of the separation is not simple and will depend on at least the following variables: where the separation is located (sidewall, shoulder, crown), the size of the separated area and depth into the tire, the carcass quality, if the tread is fabric-reinforced, on which aircraft is the tire used (main or nose position), and will the aircraft experience land or carrier-based operation.

Yes, gentlemen, we have some gray areas but we have some answers too.

Mr. Paul Vogel, and the hosting organizations, please accept our thanks and sincere appreciation for your efforts and initiative in conducting an excellent symposium. We have all appreciated the opportunity to learn, to be brought up to date, and to make some viable personal contacts. We recommend that this symposium be held again in one year.

CHAPTER VIII – PANEL DISCUSSION

PANEL MEMBERS

Charles Merhib, Moderator
Robert C. Fiorille, Dr. I. W. Ginsberg
Dr. Ralph M. Grant, Gwynn K. McConnell

Mr. Merhib: Many things have been mentioned here, and there seems to be running through each of the speakers' comments one basic thought which is to evaluate the anomalies in the tire – just what do they mean? I think this would go back to what Dr. Grant said in his talk and mentioned again here: Just what do they mean? And, of course, you're going to find out, not only do you have to locate it, but what does it mean? Is it harmful or not? Until you've reached that point, you won't get any real, meaningful data; so somewhere, somehow, you've got to establish the effects of these anomalies on the tire, and I think that goes for nondestructive testing – the whole field in general. I know there's one report the Navy put out on a brass valve which they rejected completely because radiographically it was poor. It was just loaded with porosity; it was no good. So they took that valve and subjected it to many cycles of its normal usage; they ran it through many cycles of overstressing; they just ran it and ran it, and it never failed, yet it was rejectable on the basis of its radiographic test. So the meaning of defects or the meaning of anomalies goes for the whole field of nondestructive testing, not just as applied to tires.

We have seen, as Dr. Grant pointed out, that you can get a small defect in the bead area on one tire and it would cause the tire to fail; yet, you have it on another tire, and it does not cause the tire to fail. Is that correct? Right. That sort of thing's got to be done, but who's going to do it? How can you get these programs coordinated? Who's going to pay for it? And even if they are separately funded, how can we be sure that all this information is going to come to one central source of some sort? Should you funnel it through DOT? I guess that's basically what they are doing. Are they working with the manufacturers as well?

Mr. Lavery, DOT: A very small effort.

Mr. Merhib: Do you want to make a comment?

Mr. Lavery: Basically what we are trying to do in the nondestructive testing studies is to determine what methods are applicable for measuring defects in new tires, in-service tires, and carcasses for retreading. The program is one for evaluation, and one of the major facets of the project is to try to relate defects or anomalies, or whatever people like to call them, to subsequent tire failure in the in-service mode. This type of work has been going on ever since the first tire was made; people have been trying to make them better, and I think they've been very successful at it. There are very few bad tires. The problem is not a small problem. It's a very large problem to try to identify the defects, it costs a lot of money, it takes a long time, and it's not going to be solved overnight. What we're doing is as much as we can with the resources we have available. We do work with the tire companies, and we've been very fortunate in getting very good coordination between them, ourselves, and other people in the field. I think everybody would like to see more of this type of work. I don't know the proper mechanism for doing it, but would be open to suggestions. Thank you.

Mr. Merhib: Any comments from the floor?

COMMENT: I have visited a few of the tire manufacturers and was very impressed by the fantastic in-depth knowledge that certain individuals in their research laboratories have been able to acquire in studying the defects, structures of tires, etc., interpreting these quantitatively and, generally speaking, taking a very high level of, shall we say, ivory tower type science. On the other hand, I also have the impression that, as far as applying NDT testing to production levels, the work is left in charge of people not suitably trained for this; therefore, I think that in many cases the difficulties arise in correlating the nature of defect as observed by the NDT technique and the final life or prediction of the behavior of the tire. And I would make a plea to the manufacturers of tires who could offer a tremendous amount of help in this area by instituting a suitably trained group of people who would specialize entirely in this field as a full-time project.

Mr. Roule, Goodyear: In your studies, have you come up with anything yet to tell what is going to cause failures and when?

Mr. Lavery: We really haven't gotten that far along. We're just now in the process of selecting methods which we feel will detect in a somewhat economical, reliable manner the defects which may be important and the tire failure mechanism.

The identification of these mechanisms in doing the defects correlation to ultimate tire failure is yet to be done.

Question: I think I already know the answer to this, but I wanted to ask Mr. Lavery to comment on his statement that the problem is to try to relate anomalies to failures, or what we would call anomalies. Do you mean by that expression, *defects,* and are you implying then that the word *defects* applies only to those characteristics of the tire that relate to failures?

Mr. Lavery: As I think I understand your question, we have been concentrating on defects or anomalies, whichever you prefer to call them, which should lead to ultimate tire failure. We're not looking at things such as uniformity, the radial or lateral force variation, or things of this nature. We're looking primarily at things such as porosity, poor adhesion, poor bonding on retreads – things of this nature.

Dr. Ginsberg: I would also like to ask a question of DOT. Have your people found what the property really is that causes the failure? What is the thing that causes the failure? Not things such as separation, but the physical phenomenon that causes the failure in a tire outside of a puncture.

Mr. Lavery: If we knew the answer to that, we would be essentially done on the project. However, as we see it, we have several years to go, and at that point we will still probably be very humble about it. The laboratory that we have, and the data, are open; there's nothing classified, and the people working on the project are available for discussions. The opinions they have won't necessarily be the official DOT opinion; they may be their personal opinions. But, be that as it may, hopefully the answers will be as objective and as honest as we can make them.

Dr. Winogradoff: There's a question I would like to ask about X-ray techniques. Can you give us some idea as to how to specify the ideal X-ray machine for tire inspection? The reason I'm asking this is that about a year ago I was shown a radiograph of a tire, and the main point of interest was a broken cord. I looked at it in some detail and found extreme difficulty in actually seeing any evidence of a broken cord, but the man who ran the machine was obviously an expert in it and without any effort could locate it. It turned out that the machine in question was operating with a tungsten target, and it also had beryllium windows, so that he was presumably using very wide wavelength range. Is there any advantage in going to a narrow range, and if so, would a copper target be better?

Mr. Fiorille: We find that to be a very good question, and I have done some work with other target materials. However, for that application, and as we understand the purpose and application of X-ray inspection by the manufacturers of tires, most of the systems, because of such diversified usages, have been better manufactured with a tungsten target. Not until one of the companies has come to us with a specific questionable area to be determined, do we think that we would make one specifically with a separate or distinct target characteristic. As you say, most of the equipment is provided with a tungsten target and a beryllium window for wide range and energy levels, and it's because of the wide range usage of the equipment that it's done that way.

Mr. Merhib: The comment was made that we should meet again in a year. How does the conference body here feel about that? Just think about it, please.

Dr. Grant: Before concluding, I would like to make a very brief comment on the personal experiences I have had with the rubber industry over the last seven years with holographic testing. I have been most sincerely and very deeply impressed with the objectivity and sincerity of these people in their desire to really understand the meaningfulness of defects or problems that exist in tires. Almost every major tire manufacturer, every major one in the world – in Japan, in Europe and in our country – has in some way or another significantly supported our research in holographic nondestructive testing of tires. Goodyear and Firestone along with Uniroyal and General have all really put in "their pint of blood" to understand sincerely whether our method was working, when really the method was to our advantage. We were the ones that would profit from the direct benefits; they would profit from the indirect benefits, or looking at it from their point of view, be able to better understand their tires and make better ones as a result of our test method. The point, basically, is that they are a sincere, marvelous group of people. Instead of hiding a lot of things underneath the rug, once we established rapport, they brought out the problems that they had, and in each case were dedicated to helping us to the best of their resources to find the answers that we sought. And with that I have a great deal of encouragement and optimism about the future – the basic problems that we have will take a number of years to solve, but these people will continue their strong support. Thank you.

Mr. Merhib: Well, if we have no further questions, I would like to thank the panel members for their fine work, and I would like to turn this portion of the meeting over to our chairman, Mr. Vogel.

CHAPTER IX – CLOSING REMARKS

PAUL E. J. VOGEL

Program Chairman

I never did get around to introducing Mr. Merhib properly to you. Charlie is noted in a number of fields and many of you have corresponded with him at the Nondestructive Testing Information Analysis Center, which is at the Army Materials and Mechanics Research Center in Watertown, Mass. He has published a number of papers in ultrasonics and other NDT. He's into many things including teaching.

Thank you very much, Charlie, for a fine job. As you all know, he was what amounts to the co-chairman here, and he worked with us right from the beginning. I sincerely appreciate all his help.

Before I make a few closing remarks, I would like to call on Colonel Weitner whom you have all seen. He's had to stay outside the hall and keep his hand on the registrations, but he's the representative from the American Ordnance Association. I would like to thank him and ask him for his remarks from the American Ordnance Association – Colonel Walter L. Weitner (USAF Ret).

Col. Weitner: Thank you, Paul. I feel as I know each of you gentlemen personally, having seen you come in and talked to most of you on the way in and out. We are particularly happy to have been able to support AMMRC in this meeting. This happens to be my first effort with the American Ordnance Association, having joined them in January. I hope we've done the right things along the way here. With Paul's excellent effort and that of the AMMRC people and all of you, we couldn't help but have a success. I think that the important things did happen the way they should. If not, we'll be happy to process your complaints here and learn by this meeting what to do or not to do next time. So I want to thank you.

Mr. Vogel: Thank you, Colonel Weitner. In closing, I would like to answer some questions that address themselves to our next meeting if we have one – the need for one – and if we do have one, why should any particular installation organize it.

We have a number of other people who are interested in rubber products. Within ASNT there is a Rubber Products Committee and George Halsey in Indiana, Pa., chairs this committee. He's been active in NDT but his committee goes across the board on rubber, and we are concentrating our effort on tires. Also, there is possibly some duplication with the new F-9 Committee of ASTM, but we have had a close coordination with them, and there are a number of people here who also sit on that committee.

The military traditionally has put the big dollar into R&D. The industry just cannot afford to spend the money that the military does so, in spite of what you might hear about the industry-military relationship, the big complex, and so on, from some of the street-corner newspapers, it's a necessary facet in our life. Military R&D has given you dandy little things like dehydrated food, these plastic shirts that keep riding up, jet engines, and a bunch of other things that bother environmental extremists. But at least Army-developed diesel engines keep the streets cleaner than they were when the horses were around. You can delve into history to find out what the cost of cleaning your city streets was 50 years ago compared to now, and maybe the form of pollution we have now is not too bad.

General Meyer, in his comments the other day, said how the American tire industry has done a marvelous job even though our work is still essential. As far as passenger car tires are concerned, you seldom if ever see a car by the side of the road with a flat tire unless the tire is obviously overloaded. It's usually on a station wagon – and they have to take all the stuff out of the back, and five kids out of it, and the boat off the roof, and burrow down underneath to get their flat spare tire that they haven't looked at for 2 years. And then you'll notice that the tire that's flat was a baldy to begin with – it should never have been on the ground. The average passenger car tire is a fine piece of engineering. This does not mean that NDT is not necessary in production and storage and that as the tires wear on we're not going to have to have some sort of a test, possibly, as Mr. Lavery has mentioned, on semiannual safety inspections.

Our military people have taken the lead with the Tri-Department Aircraft Tire Coordinating Committee in the safety of aircraft tires, most of which are retreaded. I rode on TWA a couple of weeks ago, and I was fortunate in that they let us walk down the ladder onto the ground instead of going out through that tube that they usually feed us in and out with. I sweet-talked the driver into letting me near one of

the main-wheels; there on the side of the tire was a little molded disc about the size of a half-dollar, and it said R-11. That tire had been retreaded 11 times and was still considered safe enough to carry $20 million worth of aircraft and 200 lives. The industry has followed the lead of the military – for the most part, the Navy and the Air Force – in the recapping of their tires. In their wisdom, the military has seen the need for nondestructive testing to ensure that the carcasses are suitable for recapping and the rebuilds are safe to use. They have been leaders in having the nondestructive testing industry orient themselves toward specific flaws which we believe, in the present state of our knowledge, to be significant in the life expectancy of a tire. So the industry people – some of the tire manufacturers who are present – have said, "Keep the lead. At least you have an impartial interest in tires and you have the manpower, so run the meetings, but just be sure that we have our say."

When I say "military", I'm talking Army, Navy, Air Force. But there is one other Government agency, the Department of Transportation, that has also been way up front both in work and highly skilled scientific and engineering abilities, and in the dollar. I heard Mr. Jim Martin from Calspan say, I think, that it was $100,000 that NHTSA put into the air-supported flat profile belt. Now that shows an interest; that's putting the money where the need is.

So, with that for background, to answer the question, "Why should the military continue to sponsor?" – this appears to me to be what the attendees here want, and my Headquarters has said, "Go ahead and commit yourself, Paul. If the attendees want another meeting, we will see to it that it is done." Asking around here today, there appeared to be three good locations, each having its different advantages for another meeting of this nature about a year from now. A call for papers would go out well in advance of the meeting, but in planning, one thing we have to know as early as possible is the place, and any suggestions from the floor are welcome. I will only offer what I've heard. We can repeat right here. Gordy Eure with Thompson in Atlanta, Georgia, has invited us, and Air Treads also has extended its welcome. These are two of the larger aircraft tire retreaders. Then there's Bandag up in Muscatine, Iowa. The third choice is Akron, Ohio, which is the heart of the rubber industry. Where Altanta would be able to take you into major rebuilding facilities, Akron would bring you into the major new tire building facilities. So you have Boston, Akron, and Atlanta. Let's have a show of hands right now assuming that we'll have enough papers to make a worthwhile meeting.

[Ed: The count was announced as Boston 14, Akron 14, Atlanta 65, and the meeting was declared adjourned.]

APPENDIX A – ATTENDANCE ROSTER

NONDESTRUCTIVE TIRE TESTING SYMPOSIUM

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
SUPPORTED BY THE
AMERICAN ORDNANCE ASSOCIATION

10-12 April 1973

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APPENDIX B — BIOGRAPHIES

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CORSTANJE, CORNELIUS, is a marketing specialist in industrial trade relations in the Radiography Markets Division of Eastman Kodak Company, Rochester, N.Y. He began his Kodak career in 1951 in the data processing department, progressing to the position of system analyst. He was appointed an accountant for the former Eastman Kodak Stores in San Francisco where he fulfilled administrative functions of office and credit manager. From 1964 through 1969, Mr. Corstanje was a radiography markets technical sales representative in southern California. Mr. Corstanje is a 1962 business administration graduate of the University of Rochester, and he has completed Kodak training in radiography sales and the Sales Analysis Institute. He is a member of the American Society for Nondestructive Testing, the American Welding Society, and the American Foundry Society.

FIORILLE, ROBERT C., is Marketing Director at Imagex, Inc., Mentor, Ohio, where he is responsible for all sales and marketing and is coordinator of all distributor activities. He has recently joined the firm and has been involved in the nondestructive testing field for the past 7 years. Previously, he was employed at Picker Corporation where he held the position of Product Marketing Manager in the Industrial Division. He is a member of the American Society for Nondestructive Testing, the American Society for Quality Control, the ASTM F-9 Committee, and the ASNT Rubber and Plastics Committee. Mr. Fiorille attended Kent State University and served with the U.S. Navy in the Pacific area for 4 years.

GAMACHE, DAVID L., BSME, Wayne State University, 1963, is with the US Army Tank-Automotive Command serving as Special Projects Officer and assistant to the chief of the Quality Assurance Division. In this position he is responsible for NDI, special test equipment, value engineering and other special projects. He is currently involved in a program to develop a pulse-echo inspection system for rebuilt Army tires. Prior to joining TACOM, he was in the Engineering Division of Chrysler Corp. in the Suspension and Steering Laboratory where he was involved in the design and development of chassis springs, ball joints and rubber bushings. He has served as chairman of the DOD NDT Conference and is very active in youth activities in Sterling Heights, Mich.

GINSBERG, IRVING WILLIAM, Ph.D., at the time of the symposium, was Staff Scientist and Vice President, Sensors, Inc., Ann Arbor, Mich., and he has since joined Philco-Ford Corp., Newport Beach, Calif. Dr. Ginsberg is a graduate of Wayne State University where he received a BA degree in Physics in 1955 and a Ph.D. in Physics in 1960. Prior to joining Sensors, Inc., he was an Associate Research Physicist from 1965 to 1969 and Research Associate, 1962 to 1963, at the University of Michigan; Senior Research Physicist, Chrysler Corporation 1963 to 1965; and Physicist, Bendix Research Systems, 1959 to 1962. His technical experience includes theoretical studies of ferrites, theoretical consideration of laser coherence, investigation into application of magnetohydrodynamics to power conversion—plasma research, application of optics to the design and specification of radiometers and scanners, analysis of interaction between EM radiation and matter on microscopic scale, and analytical simulation of electromagnetic properties of objects including emission and reflection from solids and gasses, atmospheric transmission, and signal-to-noise calculations.

GORUM, A. E., Ph.D., is Director of the Army Materials and Mechanics Research Center at Watertown, Mass. Dr. Gorum has over 20 years of extensive academic, industrial, and Government technical and managerial expertise. His broad research experience includes studies in the areas of ionic solids, processing of plutonium, plutonium alloys and similar conductor materials, physical ceramics and armor materials. He has authored numerous papers in major scientific journals. He has a BS and MS in Metallurgical Engineering and a Ph.D. earned at the University of California.

GRANT, RALPH M., Ph.D., is Adjunct Professor at Oakland University College of Engineering, Rochester, Mich. In 1966, Dr. Grant founded GC Optronics, Inc., Ann Arbor, Mich., serving as President and Technical Director. Under his guidance, GCO made significant advances in the field of holography and has become the nation's first independent organization totally engaged in the field of holography (1966 to 1972). He received his BS degree in Engineering Mathematics in 1959 at the University of Michigan where he also received his MS degree in Nuclear Engineering in 1961. In 1964, he received his Ph.D. in Physics at the Technical University of the Netherlands, Delft. During 1969, Dr. Grant's achievement on conceiving and perfecting Applications of Holography

resulted in his receiving the "Achievement Award" from the American Society for Nondestructive Testing.

KAPLAN, HERBERT, is Director of Advanced Applications, Barnes Engineering Company, Stamford, Conn. He received his BSEE in 1952 from Brooklyn Polytechnic Institute and did graduate work in Business Administration and computers at BPI and NYU. Mr. Kaplan has extensive engineering experience in computers, simulators, training devices, and infrared instrumentation. He joined BEC in 1963 and has been involved in applications engineering in infrared and electro-optics for 9 years. He is a member of the Instrument Society of America, the American Society for Nondestructive Testing, and the Society of Photo-Optical Instrumentation Engineers.

LAVERY, ADELBERT, is Chief, Electromechanical Branch, Transportation Systems Center, Department of Transportation, Cambridge, Mass. In this capacity he is responsible for several safety related ground transportation programs, one of which is the nondestructive testing of tires. Mr. Lavery received his BSEE from Renssalear Polytechnic Institute in 1959. He worked for several years at Douglas Aircraft Company in their Testing Division. Later he worked as a program manager on several electro-optical remote sensing programs for a small Cambridge company. In 1966, he joined the NASA Electronics Research Center and was later appointed as Chief of the Bio-Instrumentation Branch. In 1970, he joined the Department of Transportation.

LORANGER, W.F., Ph.D., received his Ph.D. in Applied X-Rays at the University of Illinois in 1952 and has been actively engaged in the X-ray field since that time, including diffraction, fluorescence, radiography, and electron probe analysis. After serving in the Air Force at the Wright Development Center and the US Military Academy at West Point, he spent 6 years with General Electric X-Ray and another 11 years with Picker X-Ray. He has also been an active teacher having served on the faculties of three state universities as well as being responsible for corporate training programs. Dr. Loranger joined Xerox-Xeroradiography in April 1972 as Industrial Market Manager. He is a member of many professional and academic societies and has been widely published in the applied X-ray field.

MARTIN, JAMES F., is Manager of Tire Research, Vehicle Research Department, Calspan Corporation, formerly known as Cornell Aeronautical Laboratory. Mr. Martin has been with the Vehicle Research Department since 1970, and he is involved with the design and construction of the Tire Research Facility. He is a graduate of the University of Minnesota with a BS in Aeronautical Engineering.

McCAULEY, P. T., holds an AB from Washington & Lee University, Lexington, Virginia. He was previously with Motorola, Inc., where he was Assistant Marketing Manager for 7 years in microwave communication and industrial controls. He was also with Micro-Dyne., Inc., President and Director of Engineering for 15 years, where he specialized in instrumentation, process control, and special purpose digital computers. Mr. McCauley is now with James Electronics where for the past 5 years he has held the position of Vice President of Engineering and General Manager in the Instrumentation Division. He is specializing in low-frequency ultrasonic NDT, ultrasonic imaging, and various industrial ultrasonic applications with their related equipment.

McCONNELL, GWYNN K., serves as a Nondestructive Inspection Specialist, Air Vehicle Technology Department, Naval Air Development Center, Warminster, Penn. He is responsible for the development and application of nondestructive inspection methods for military aircraft. He is a graduate of Temple University with an Associate Degree in Electronics and he has had over 20 years of experience in various areas of research and development. Mr. McConnell is the author of several technical papers in his field.

MERHIB, CHARLES P., has served with the Army Materials and Mechanics Research Center for over 11 years, first in ultrasonic research and more recently as Chief, Nondestructive Testing Information Analysis Center. Earlier he was with the US Army Natick Labs for 5 years as a physicist in the Physical Testing Laboratory, and prior to that he worked at the development of infrared night vision devices at the Army's Corps of Engineers R&D Laboratories, Fort Belvoir, Virginia. He is a 1951 graduate of the University of Massachusetts with a BS in Physics and has continued his studies in universities in the Boston area. Mr. Merhib has two patents and numerous publications to his credit and has served as Program Chairman and Yearbook Chairman of the Boston Section of the American Society for Nondestructive Testing.

MEYER, RICHARD D., LTG (USA Ret), serves as Assistant to the President, Firestone Tire & Rubber Company, Akron, Ohio. In that position he is responsible for the supervision of the management system by which new tire products are brought into development, production, and inventory. General Meyer is a graduate of the US Military Academy, 1933, and did postgraduate work at the University of California where he received his MS in civil engineering. He is a graduate of the National War College and has been an Army aviator since 1957. He served in a number of logistical positions including Commander of the Port of Manila in World War II, G-4 of the Eighth Army during the Korean War, Director of

Plans for Deputy Chief of Staff for Logistics, and DCSLOG for US Continental Army. His last assignment was Director of Logistics, J-4, Joint Staff of the Joint Chiefs of Staff from 1963 to 1967.

NEUHAUS, TED G., is Tire Systems Sales Manager for Picker Corporation, Cleveland, Ohio. He has been in the field of industrial and tire X-ray since his graduation from Ohio University, Athens, Ohio, BS, 1956. Prior to his present position he held positions of Sales Engineer and Marketing Research Manager. He has been an active member of ASNT, ASTM, ACS and ASQC and has presented papers to local and national meetings and educational programs. Mr. Neuhaus' most recent contribution to the tire industry, patent applied for, is the air-inflated, bead-to-bead inspection, X-ray production system.

PAVLIK, CHARLES J., serves in the Aircraft Tire Engineering Group at Hill AFB, Ogden, Utah, where his work includes field operational problems, qualification and test procedures, quality control, and liaison with various Air Force Commands in tire problems. He received his BS in Chemical Engineering at Iowa State College in 1945, and from then until 1962 worked in R&D with Gates Rubber, Denver, in material compounding, product development including truck tires and automotive hose, pilot plant field testing, and as technical service representative. His major effort for the past 4 years has been in the Tri-Service High-Performance Aircraft Tire Coordinating Committee, where he has served continuously as the Chairman of the Rebuilding Committee.

PETRICK, ERNEST N., Ph.D., is Chief Scientist of the US Army Tank-Automotive Command in Warren, Mich. A native of Pennsylvania, Dr. Petrick received a BS degree in Mechanical Engineering from Carnegie Tech in 1943. He served in the Navy until 1946 as Chief Engineer of a destroyer and later held the rank of Lieutenant Commander in the US Naval Reserve. He taught in the Departments of Mechanical and Aeronautical Engineering at Purdue from 1946 to 1953, where he also supervised the Gas Turbine Laboratory at the Purdue Jet Propulsion Center, and where he received MS and Ph.D. degrees in the field of heat transfer in air-cooled gas turbine engines. In 1953 he joined Curtiss-Wright Corporation and served as Chief, Advanced Propulsion Systems; then later, from 1960 to 1965, he was Chief Engineer at Kelsey-Hayes Company, Detroit, with responsibility for aerospace and automotive research activities including the development of automotive disc brakes. He has been noted in *World's Who's Who in Commerce and Industry, American Men of Science,* and *Who's Who in the Midwest.*

THOMSON, CLARENCE, a nondestructive testing engineer with the Ogden Air Materiel Agency, Hill AFB, Ogden, Utah, is a 1946 graduate of the University of Utah with a BS in Metallurgical Engineering. After serving in the Army in Korea (1950 to 1952), he was in materials testing with ALCOA in Los Angeles until 1954 and with the NDT Laboratory at Hill AFB from 1955 to 1957. He then set up the Chemical and Physical Testing Laboratory at Marquardt Aircraft, 1957 to 1960, on Bomarc ramjets, then moved on to Utah R&D in Salt Lake City in the NDI Lab. He has now been with Hill AFB since 1964 in the field of NDI and failure analysis; he is a member of the Greater Salt Lake Chapter of ASNT and is past-secretary of the local ASM group.

VAN VALKENBURG, H. E., is Manager, Applications Research at Sperry Division of Automation Industries, Inc., in Danbury, Conn. He is a graduate of Union College with a BS in Electrical Engineering. Previous positions include 7 years in the instrument laboratories of the General Electric Company. Nondestructive testing, especially related ultrasonic technology, has been of principal interest for 25 years. The application of these techniques to diagnostic medicine has been a recent responsibility. He has published numerous technical papers and holds 20 patents in the NDT field. Mr. Van Valkenberg is active in technical societies concerned with calibration and standardization problems, serving on committees of ASTM, ASNT, and IEEE.

VOGEL, PAUL E.J., P.E., serves as a Research Mechanical Engineer at the US Army Materials and Mechanics Research Center, Watertown, Mass., where he joined the professional staff in 1962 as a member of the Nondestructive Testing Branch after graduating from US Army Command & General Staff College, Fort Leavenworth, Kansas. In his specialty of infrared, he has authored over 25 papers in addition to others in the fields of ultrasonics and acoustical holography and in broad applications of NDT. His most recent publication is *The State of the Art of Nondestructive Testing of Tires* (AMMRC PTR 73-9). He is active in the American Society for Nondestructive Testing where he is chairman of the Committee on Infrared Techniques for Materials Evaluation, and ASNT Handbook Coordinator for infrared and thermal testing. He also serves as a Scholarship Sponsor in the Boston Post of the Society of American Military Engineers; is active in the Army Reserve in the rank of Colonel; and is a historian in his adopted town of Marshfield, Mass., where he is chairman of the Daniel Webster Historical Society.

WARREN, CLIFTON, is Technical Sales Consultant and Midwest Sales Manager for AGA Corporation, Secaucus, N.J., a

subsidiary of AGA AB, Sweden. Mr. Warren attended schools in New York, California, Delaware, Hawaii and Michigan where he was last working toward a Ph.D. in Remote Sensing. While at Michigan, he was Research Assistant at the University's Willow Run Laboratory, Infrared and Optics Division. His specialty interests include airborne remote sensing, glass, petrochemical, void and flaw, automotive and data processing applications.

WINOGRADOFF, NICHOLAS, Ph.D., received his Ph.D. at Edinburgh University, Scotland, where he specialized in radiation physics. He joined the IBM Research Laboratories in the USA in 1958 and received an IBM Invention Award for work in radiation detectors and lasers. In 1964 he transferred to the National Bureau of Standards where he served as a research physicist and laser coordinator. Dr. Winogradoff is currently the Head, Test Development Group, Tire Systems Division, Safety Systems Labora' ory, National Highway Transportation Safety Administration, Washington, D.C. He is the author of 26 papers, chairman of one of the ANSI Z-136 subcommittees on laser safety, and is a Fellow of the British Institute of Physics and the Physical Society.

✱ U.S. GOVERNMENT PRINTING OFFICE:1974 702-816

NTIAC 75-1

PROCEEDINGS OF THE SECOND SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

Sponsored by
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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Editor

PAUL E. J. VOGEL

Materials Manufacturing & Testing Technology Division
Army Materials and Mechanics Research Center

1-3 October 1974

Atlanta American Hotel, Atlanta, Georgia

Sponsored by

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

• PROCEEDINGS

This document was published by the Department of Defense Nondestructive Testing Information Analysis Center (NTIAC), Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172. NTIAC's Mission is the collection, maintenance, and dissemination of information in the field of Nondestructive Testing.

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CHAPTER I – OPENING OF THE SYMPOSIUM

CITY OF ATLANTA

MAYNARD JACKSON
MAYOR

October 1, 1974

Symposium on Nondestructive Testing of Tires
Atlanta American Hotel
Georgian Ballroom
Atlanta, Georgia

Greetings:

It is my pleasure to welcome delegates to the Symposium on Nondestructive Testing of Tires. I regret that due to a previously scheduled engagement, I am unable to appear before you personally to welcome you to Atlanta.

I am sure that you will be busy with a full schedule of meetings, discussions and seminars. I would, however, like to urge you to take the time to see our city. We are proud of our growing reputation as a national convention center as well as our long established reputation for southern hospitality. I am sure that if you have the time to see our city and meet her people you will not be disappointed.

Best wishes for a pleasant and productive conference.

Yours for Atlanta,

Maynard Jackson

MAYNARD JACKSON

MJ:ff

OPENING REMARKS

LTC Robert B. Henry
Commander, Army Materials & Mechanics
Research Center, Watertown, Mass.

On behalf of the Army Materials and Mechanics Research Center, I wish to extend best wishes for a successful meeting. This second symposium on nondestructive testing of tires also happens to be the second major symposium conducted in the past month by the Nondestructive Testing Information Analysis Center . . . or "NTIAC" as shown in the logo on your program. This sort of activity is part of the mission that was assigned to NTIAC by Department of Defense through Headquarters, Army Materiel Command, and you are all familiar with the general mission from the write-up in the meeting announcement.

We are most pleased with the fine representation here from the other Services, –other Government agencies, –the new tire industry, –their suppliers, –the tire rebuilders, –the nondestructive testing equipment community, –and, as a frequent and sometimes "white-knuckled" traveler, I find the participation of so many airline representatives particularly heart-warming.

We are also very grateful to the speakers who have come great distances to publish their reports of advances in the conventional methods of nondestructive testing technology as well as in the unusual techniques such as you will hear of in Mr. Boutaine's very interesting peaceful application of atomic energy.

By your presence, you are contributing greatly to our efforts in the collection of NDT information, and, with the cooperation of the authors, we will be able to disseminate this information without delay by publishing the PROCEEDINGS at the earliest possible date. The first PROCEEDINGS is an outstanding document that is now available. I am as anxious as you are to get on to the keynote address and the papers, so I will not delay you further. Again, I know that each of you will find this meeting most rewarding. My staff and I will be at your service for your entire stay here and we will be most attentive to your needs or comments.

CHAPTER II – KEYNOTE SESSION

KEYNOTE ADDRESS

Philip D. Johnson
Director, American Society for
Nondestructive Testing

Let's talk a little bit about how this nation got started. First of all, this United States of ours was founded as a nation of farmers. Ninety-nine percent of the American public at the turn of the 17th century were farmers. George Washington was born of a farming family and if it were not for the fact that he had two elder brothers, he would have inherited his family plantation. But since he was not the eldest son, the farm was presented to his brother and he went out into the professional field. This is the way a second or third son could make a living, namely to become a professional and he became a surveyor as you well know. Now the second President of the United States was John Adams, son of a farmer, and he wanted to be a farmer himself and his father said this was no job for a young man in this country of ours. We have plenty of land and he sent him up to a very small school in that cold country up north called Harvard and he became a preacher. At the age of 15, he had a degree in the ministry. At 20, he had a degree in law. He went on into politics and became the second President and father of another.

After the American Revolution, the economic picture passed from the shoulders of the American people. It was thrown off and thousands then left the farms and went into small industry. Because under the British, there were no rights given to the American people to make certain things–chinaware could not be made, ships could not be built except by British firms–everything that was manufactured was bought from England and the balance of trade had to be in the favor of some other country. All of a sudden professionalism bloomed in this country and we became a nation of self-made people. Everyone was self-made. There was plenty of water power, plenty of wood, lumber, coal, wool, cotton, minerals, so small factories went up by the thousands and bloomed like flowers in the spring. The self-made man came into his being. The trades and crafts followed the old English system and the Germanic system of what we like to call apprenticeship which is no more in this country. Now some people may say 'oh yes we have an apprentice system but it is frowned on by most people'. The so-called schools, what we used to have in my time as a young man, the schools of vocational training were for the fellows who couldn't quite make it into the regular high school or regular junior high school. They went into a vocational school and forever made bookends and breadboards. But the crafters under the apprentice system served at least a four year apprenticeship and sometimes seven depending on the line that they were in. Often times before the fellow finished his apprenticeship he had to make the tools of his trade–the tools of his craft by his own hands and so some of you can remember seeing in your grandfather's home some hand-made tools–some wooden tools. For centuries American products of these craftsmen were the envy of the world and they are now classified as worth billions of dollars and called antiques. Today things are made at a much faster pace.

The American Revolution was fought and won with flintlocks. Many of these flintlocks were made by the owner. But along came our Civil War, Spanish-American War, World Wars I and II, the Korean War and the Vietnamese problem. They were frought with man-induced problems of poor ammunition. Today's military shells are suspect to the tune of who knows what and this is a full story in itself for people in nondestructive testing.

I have had a lifetime of interest in tires, I've changed more tires than many people here because of my age. But I can remember my father having a car right after the first World War and he had a set of tires on that car and they were 'pistols'. They were called Pennsylvania Vacuum Cup Tires and when we first had paved roads up in New England, they would sing like an opera singer. I don't know if any of you remember the tire called the Pennsylvania Vacuum Cup Tire but it was something. Now tires are a commodity that are made today in daily quantities that stagger the imagination. Now I've talked to a number of people specifically on this point to find out how many tires are made in this country in a day and they range all the way from 200,000 to 480,000 and this is based on the output of five major tire companies. Now if there are anywhere from a half a million tires made in a day, who can inspect them? And those that are inspected will go into the hands and ownership of those that are interested in good tires–the manufacturers of tires–the manufacturers of cars. They are not made up of components easily tested–either alone or compounded and the manner

in which they are made is a mystery. Certainly a mystery to 100 percent of the American public and it is only in advertisements in the magazine and newspapers in the last few months, last few years–let's say two years have they shown you what purports to be the guts of a tire and these are artists conceptions of perfectly overlaid material–one over another.

Since this is homogeneous material it lends itself to be tested by any one, two, three method of testing. It itself is a mystery as to how they can possibly be tested. When you stop and think that the earliest method of materials examination or materials evaluation was a Southern invention–it was invented in a nearby state called Tennessee and this was pokeberry juice and chalkdust and then it was taken up by some people who later became the Magnaflux Corporation and they formed a method called 'penetrant' and another method called 'magnetic particle testing'. These are followed by, in the order of, gamma ray and then by x-ray examination but limited in the imperfection in the available screens first and then the slowness of the film and the film processing in the radiographic field. Now of late other methods of nondestructive testing have come to the fore some so dazzling by name and method that they scare the folks in industry almost out of their chairs. When you stop to think someone says "holography"–and you are going to hear about that, "interferometry"–you're going to hear probably today, then you go over into the real fascinating fields of 'micro' and 'macro' testing, it's enough to scare you. Actually, testing as we understand it is the extension of the human senses–touch, smell, taste, sound and even eyeballing. I remember a few years ago when the Second Navy–there's the United States Navy and then there's Admiral Rickover's Navy, when he found some problems in some tubing, whether it was extruded tubing, whether it was flawless tubing, whether it was seamless tubing, and they went through thousands of dollars in one day of telephones and telegrams across the country to all kinds of experts trying to delineate these two or three types of tubing and find if the right kind had gone into this particular early nuclear sub. When the whole thing was all over, somebody with a snap gage could have told the difference between these tubings because of the diameter changes–the differences in diameter. So we don't stop to think of eyeballing as a method of examination, but it is–is it here? is it brown? is it square? is it red? is it blue? is it the proper number?

Many of these were developed for single application but then industry comes along–its "they" up in Building 39–"they" are always to blame–say that you must use this as a universal tool so everyone wants to be able to say that their particular method of testing is a universal tool and can be used for everything.

You know all of a sudden American goods are being branded as a poor quality. To think that American products caused the category of what we use to call "Foreign Junk" seems almost irreligious but it's true and the bad thing about it is that we can mass produce it. A few years ago just before the influx of the solid state electronics, we had two companies, RCA and Texas Instruments, who were producing the majority of the electronic tubes used in our country–the little radio tubes of whatever size–and it was said by both of these companies in some of their reports and in private reports that they had rejection rates equalling 55 percent. Can you imagine the output of a company as large as RCA, the tube manufacturer of that time, with a 55 percent in-house rejection rate. No wonder we're going into a recession! For instance, you are old enough and can remember–it's not so far back in history, you can witness the great joy that was on the face of John Glenn when he sat in that little tiny rocket–the little section on the top of the rocket–that was to take him on the first trip around the earth. What a great sense of satisfaction that he had by knowing that thing underneath him was built by the lowest bidder and when you think of how real little experience we had and the speed with which they were produced, how little nondestructive testing was actually used at that time. Now you and I do not have to be technical wizards to know something is wrong. Someone says I can't lay an egg, but I can tell when one is rotten. This is the answer we get from people who say it takes a long time for experimentation and learning to be cognizant in the field of inspection, in the field of materials evaluation, this field of my interest–nondestructive testing. It doesn't take long, it just takes a certain type of person, who has a great deal of perception, who has a great deal of interest. When a layman, that is, a layman to industry, can write a novel like the book WHEELS, and you from reading find that you'd better not accept a car that was made on Monday or Friday, that you'd better have a car that was made on a Tuesday, Wednesday or Thursday, perhaps not early Tuesday morning or late Thursday afternoon. Read that book and after you have read that book you will figure something has to be done about quality control in the automotive field. We need highly trained people to do the inspection work performed by poorly trained mechanics and craftsmen today.

The philosophy of "it's good enough" is not good enough. It's <u>not</u> good enough. We need training for nondestructive testing personnel that will put the engineer and technician beyond the reach of the production department. We have the training material but lack time, so industry says. We need nondestructive testing personnel who understand every manufacturing procedure. Now we take a guy who is pushing a broom today and we make him a technician tomorrow and he is an expert the third day. This, we cannot go with.

Now I believe in telling it as I see it and I believe we are in need of personnel who will stand up and be counted to fight the laissez-faire syndrome that has covered this country. Everybody says this—"let the other guy make up for what I missed, for what I have not done." Let someone else take the blame. Now it does stop. It's like Harry Truman says, the buck goes so far, let it stop now. Let us give these people who do the inspection, who do the evaluation of our products, give them some power, give them the strength, give them the right to say yes or no.

I saw a place just the other day in San Diego where a man who heads up a large department of ultrasonic testing in one of the largest of the rocket manufacturers in America was given two technicians who had never seen an ultrasonic unit before, who had never seen the inside of that laboratory, but because their union rating made them laboratory technicians. With three years of history—history not experience, they were put on the job. My friend tells me it takes him almost a year to train these so called highly paid or in-training technical personnel to do the job he wants to do. This syndrome that I mentioned is the philosophy of don't break your back, someone else will correct the error. This is not good enough for Americans who pay a high dollar for every item that they purchase. And random sampling under the statistical analysis method won't satisfy my need, my personal need, for an A-1 perfect steering knuckle on my car because I drive faster than anyone in America except race car drivers. And the fact that you can take this binomial theorem probability demonstrator and prove beyond a doubt that everytime you tip this thing down the same number of balls will go into every slot is not proof to me that the steering knuckle on my car is going to be satisfactory because they do come mathematically the same everytime but you will never find two steering knuckles of the same clan made the same way come out the same. Bean bag tossing perhaps may be for some but not for me.

New techniques in nondestructive testing appear daily, new techniques being devised for specific problems. Let me show you one piece of material that almost defies an inspector to prove the right to say that it was perfect for use. This is aluminum honeycomb. Now you think you have a problem in the tire manufacturing field, but here is a material that is made up together in the solid group or solid state and it is made as big,—as cheap,—as thick as they want it. It took a sharpy—a fourteen year old kid to discover that if they built this thing to the size they want it, filled it with water, it could be machined and then put into the shape they want it. But you take that and just see how you're going to test that stuff to see how the bonding is on that. That is a little bit of a problem.

Another piece I have with me is a small electronic wafer, 1/16" by 1/8", with many, many feet of circuitry. Now you're all aware of what circuitry is on a larger scale but on a smaller scale, a fellow up in Boston figured the only way he could test this was to x-ray it. Now you say, you damn fool, you can't x-ray one for one a little thing like that—what would you see? Nothing more than what you see on the original piece with a microscope. He x-rayed it on a single emulsion piece of film, on a piece of glass and he came up with a one to one x-ray, he enlarged it 17 times and still could see almost nothing. He enlarged it further to 14 x 17 and you will find two breaks in the circuitry. This was a good technique developed by a young man in the lab today. Something "they" said couldn't be done.

In tires, —and you must have problems or you wouldn't be here,—just think there are over 275 well known methods of NDT and you have a wide open field to try to find that method that satisfies you, you inspectors, whatever you want to call your titles and I love the titles they give you people around the country. I said to one fellow, what is your title and he said I am a catastrophic failure analyst and I said what is that and he said I only concern myself with losses of a million dollars or more. I figure I had better get myself a more expensive car.

We must never be satisfied with any one method of testing or materials evaluation and we must continue to monitor the manufacturing processes for ever and ever and ever, Amen. Thank you.

BANQUET–ADDRESS

Mr. John D. Blanchard
Assistant Deputy for Materiel Acquisition
Army Materiel Command
Washington, D.C.

Good evening, Ladies and Gentlemen, I'd like to begin by thanking you for inviting me here this evening. It is always a pleasure to return to Atlanta. I think it's a double pleasure to join a group of so many people. – many old friends of the Army here in the city of Atlanta. I'd like to put you at ease on a couple of counts right from the beginning. The first is that I've prepared a couple of talks, the first one would take about 20 minutes and the second one would go about 40 minutes. I've opted for the one that would only take about 20 minutes. You see it's the same talk, in one I lose my place a lot. We'll go for the first one. On the second count I'd like to advise you that I bring no coals to Newcastle. I'm not about to underwhelm you with some Washingtonese testing and I can assure you that the experts we have in Washington these days on tires are those that are experts in spare tires that some of us carry around and having made an analogy like that, I'm not about to mention anything about non-destructive testing and we can go from there.

In a more serious vein, Ladies and Gentlemen, we in the Army today are wrestling with the identical problems that perhaps each of us as private citizens and public consumers have. We have to cope with inflation, pollution, energy crisis, material shortages and, above all, dollar shortages, – and dollar shortages lead to credibility gaps. While coping with all of that, we have to keep first in mind that we are responsible for maintaining a military capability that can respond to any reasonably postulated threat. We do have a pressing money problem. Wherever we look, there's a money problem and I need not remind any of you of the problems of the recent price rises in some of the consumer products – sugar, and all sugar-based products. Look at what's happened to the price of antifreeze? Every citizen in the streets is aware of these price boosts, yet not many are acutely aware of the significant rise in the cost of Army manpower and weapon systems, nor is the average citizen aware that most of our money is needed simply for people – military and civilian. It is the remainder of the Army budget that is available to procure research, development, production, maintenance, supplies, construction, transportation and a myriad of other things that we need to keep an Army in combat-ready condition. To put it very bluntly, unless we find ways to cut the cost of weaponry and the cost of logistic support, we simply cannot afford the weapons that we believe we have to have.

Tonight, I would like to briefly share with you some of the approaches we are taking, some of the policies we are following in trying to live with the problem of ever-decreasing resources. I divert from the talk for a minute and we simply look at the same dollar figures and look at purchasing power. We immediately begin to see the context of the remark of decreasing resources. A lot of the people in the public domain won't take that step and they look at total dollar figures but I think it is evident to all of us in all your work that you are doing. When we look at the same dollar and look at the job they have to do, it's in that context that we suffer the greatest loss in terms of dollars to get the job done.

I dwell on some of our unborn plans, acquisition of weapon systems, and equipment and I distinguish that from the people part of the problem because it is weapon systems and equipment that the Army Materiel Command is concerned with. New systems still on the drawing boards are being designed to save manpower. In many cases, machines can take the place of people.

Getting back again to the cast of people as one of the primary users of the resource dollar, the SAM-D, our air defense system, with its vastly increased capability, will use only about 1/3 of the manpower that is presently needed for the emplaced Hercules and Hawk systems. It is no secret that our costs have and, to some extent continue, to exceed initial estimates for the SAM-D system.

In the era of severe budgetary pressures, we will in the future be relying more on upgrading of weapon systems capability rather than seeking quantum jumps in technology. It's simply too costly to attempt state-of-the-art increases in capability on each trip back to the development laboratory.

Secondly, we are designing systems that must last longer, work better, be easier to maintain in the field, and require fewer overhauls before they are replaced. In fact using a concept of modular building blocks, we're hoping that major overhauls will not be required at all on some of our new systems. On the matter of good reliable equipment, let me point out the kind of savings that can be realized. It costs about $570 million annually to maintain the tactical vehicle fleet of trucks, jeeps and the like. We spend some 52 million manhours to get that job done. The combat fleet, some 21,000 vehicles, including tanks, troop carriers, etc., cost us $310 million to maintain with just over some 8 million manhours of work. Just so you're not lost in the arithmetic, it adds up to simply a cost of some $880 million a year to maintain the Army's vehicle fleet. Now, if we could reduce our maintenance burden by 10 percent, obviously we could save $88 million a year, and I've dealt with only the vehicle fleet. Ten percent is not an unrealistic objective. Similar cases of savings could be made for missiles, aircraft, communications and other systems.

More simply stated, you just cannot cut down the maintenance burden if the equipment furnished to the field does not hold up and is usually in for repair. On the other hand, if it is reliable and maintainable, it usually lasts longer, you don't need as many spare parts and you don't need nearly as many people to keep it going.

I mentioned reliable and maintainable or RAM as we call it in the Army is on a first name basis with the Army troops everywhere. We live by it. It's a pacing consideration in deciding whether to invest the dollars required to produce each new weapon system. If a weapon cannot be judged both reliable and maintainable during development, the project is either sent back to the drawing board or abandoned. RAM is a part of every major equipment. The reliability and maintainability growth curve, considerations for reliability and maintainability have never received the attention that they receive at the present time in each of our development plans for new equipment.

We can no longer rely on promises, however, eloquently spoken and suffer distressing failures when the weapon is put into the hands of the field user. Now, they are somewhat harsh words but we've had some cases, some specific instances, too many as a matter of fact, that cause us to make those statements. The equation demands a choice between weapons quantity at the expense of weapons quality, we would invariably opt for quality and our people are becoming more disciplined to withstand the pressure of unrealistic schedules. Unrealistic schedules which have plagued us in the past, to move the equipment on to the next phase of development even though we really hadn't fully done the job in the first place.

At the same time, we've got to be careful not to engage in technical procrastination with the search for the best always defeating a very good design. We stop too long sometimes when we should move on with a good design. We can't afford hundreds of radars for the field with a mean time between failure rates demonstrated at 50 percent of that promised in the development requirement. And it's little comfort to note that a field modification can be developed for such items. Field fixtures and retrofits are seldom easy and always costly. I believe, however, that we're learning our lesson. The school of hard experience, if nothing else, is thorough. We now have a sound approach to RAM and that approach is working. Our weapon systems are being designed with clearly spelled out reliability and maintainability goals right from the beginning. I mean goals not only for the overall system but for critical components as well and in our development contracts, we require the contractors establish measurable RAM programs. At the same time, we understand that reliability and maintainability are not for free. There is an implication when we talk of RAM and it is that we simply expect more and are not willing to pay more. That is not the case. We recognize that there are special disciplines involved and they come at a cost. We have found that the real key to getting reliable and maintainable weapons is in the establishment of a sound RAM demonstration test program. In just plain practical terms, testing is the proof of the pudding and need I say that too loudly to this group. But it is a part of the RAM program wher ver we implement that program to try to do a better job in the testing and yet the cost of test programs that fully portray components, subsystems, system performance of RAM across the board are dollars well spent. Every attempt is made to duplicate or simulate the potential field conditions that the weapon will face. It's a sad commentary on the past but the basis of a firm resolve for the future that the soldier in the field must not be the first to detect design or manufacturing shortcoming. That is our job. It starts right at the beginning of the development cycle.

I recognize I've given you a somewhat oversimplified view of the attitudes toward reliability requirements for new systems, but perhaps even more significant in many respects are some of the positive programs that we've already developed to upgrade the enormous variety of weapons and equipment that are a part of the existing Army inventory. We know for sure that many of our equipments will have longer lives than originally contemplated. For example, the ¼ tone and 1¼ ton truck

were originally fielded with the attempt not to overhaul those vehicles. We are, of course, overhauling them. We have no choice. It is simply a matter of making do and making the economic choice to use those vehicles and to use them at an overhaul price that would put dollars back into the inventory that we can use for other equipment. We are now overhauling the ¼ ton and 1¼ ton vehicle.

We've got to look at product improvements in all our equipment with possible substitutes for new product development. A new system with its pressure pushing technology is always risky and is usually a costly undertaking. On the other hand, marginal or cosmetic improvements to outdated gear must be avoided. I recognize that we have talked on the one hand of product improvement and on the other we can't just simply do a cosmetic job on existing equipment. Those are going to involve some tough decisions, some very tough decisions, but I think we're going to see considerably more product growth. More use out of existing technology. As opposed to beginning at the beginning simply because of the squeeze on dollars. In the delicate land of product improvement vs. new systems, again the basic question is the same for any other of our undertakings and that is where is the biggest payoff. In dealing with the question as a general proposition we initiated a program with the acronym, RISE, or Reliability Improvement of Selected Equipment with the basic idea being to identify those components that have been the major contributor to performance failures and higher logistics costs. Then we do an engineering analysis to determine if reliability improvements will correct the problem and if the answer is yes, we move up. We have found in many instances with a modest research and development investment we can sometimes achieve really meaningful maintenance support cost savings. We have, as I've indicated previously, some handsome returns from this effort. When we sum it all up ladies and gentlemen, there can be little question that both the Army and the public consumer are really searching for the same product attributes. There is not a great deal of mystery in what we are really looking for. I'll mention a ½ dozen product attributes and see if you won't agree with me. It is simply the same in all that you do. The first would be that we both want a product that works when we are ready to use it, the second that we both want a product that will continue to work for a reasonable period of time. Third, we want a product that is safe for use in it's intended purpose. Fourth, we want a product that is easy repairable when it does break down. Fifth, we both want a product that carries with it the reputation of the manufacturer and I would underline that reputation of a manufacturer and the manufacturer must stand behind his product. And we both want a product that will give fair value for the price that we pay for it.

I think we can use those guidelines on many consumer products you buy and you can extend that to the most sophisticated weapon system and we are still talking about the same attributes of the product or weapon system.

Before I close, I want to switch subjects for just a moment and leave you with a few comments on the new attitudes on freer communications that the Army is seeking in its day-to-day dealings with industry. We in the Army are taking a hard look at what has been termed as "We know it all" Army attitude. We're looking to industry as never before for alternatives that will give us good products at lower costs. We know if that is to happen we must be ready to speak with complete candor in all of our discussions and all of our evaluations and we encourage contractors to give us ideas early in the game when we are in the best position to do something with them. It is much less costly to implement a new design while it's in the paper stage; the production line is no place to be eager with changes. Some significant investments have been made in our attempts to establish better working relationships between ourselves and Army contractors. It was here in Atlanta on the 30 and 31 of May this year that we held a 2-day symposium with almost 200 of the largest dollar volume contractors doing business with the Army. The Undersecretary and the assistant Chief of the Army for Research and Development participated in that meeting together with the entire AMC Command Group. At the meeting Gen. Miley, Commanding General of AMC, made it clear that the Army's developer and producer communities are making a special effort to listen attentively to the advice and commentary of defense contractors in dealing with our problem of shrinking resources. The principle purpose of the meeting was to open the lines of communication between contractors and Army acquisition people. I do believe that those lines are open. We have had follow-up meetings. There's an aura of candidness and openness in discussion that has not been the case for some years.

We must continue that good beginning and the Army needs your help. We cannot look inward to the solution of all of our problems. If you have any ideas that you believe may benefit the Army, the door is open. If you think you have a real money saver, I repeat, the door is open.

I would like to add at this point that the industrial environment is guided by an expression of ROI, or return on investment. It's quantifiable in dollars and cents. In the

Army, we also have an ROI but the return cannot be measured in terms of dollars and cents. We measure our return on investment in terms of the confidence that the soldiers have in the weapons that we put in their hands.

The most reliable weapon in the world is a failure if the soldier is not confident that it will do the job when he uses it. I suggest our job is to provide the weapons that will gain his respect and his confidence.

I close by expressing a simple belief that the soldier in the field deserves nothing less and I think you will all join me in that. I wish you well in your deliberation for the remainder of the symposium and thank you very much for attention and I would finish by saying, that if there is a question or two on any of the remarks I've made I would be glad to deal with them.

CHAPTER III – GENERAL SESSION

NDT AND TIRES

J. M. Forney
The Goodyear Tire & Rubber Company

WHY THE CONCERN WITH NDT OF TIRES

The population of the United States has historically been independent. We do not like being restricted by schedules and inflexible regulations.

As the automobile was developed from a mechanical plaything to a promising means of transport for the individual, people moved to it in wholesale quantities, thus showing their freedom from, and independence of, scheduled public transportation. In so doing they were willing to accept what technology of the times could provide in the way of reliability.

The same kind of independence and flexibility of scheduling was accepted in the commercial field as well. The pneumatic tire, which had contributed to this flexibility and mobility, was accepted as satisfactory because it performed as advertised.

As the first generation of motorists passed from the scene we had the first large publicly financed highway program. Accompanying the improved roads were improved vehicles and improved tires. Tire service mileage increased from around two thousand to six or eight thousand and the motorist was pleased with this performance because he knew it was the best available. Tire service life was continually improved to the point where the average motorist was able to obtain 20,000 to 30,000 miles per set. In the 1960s we started another program of publicly financed high-speed highways and the motorist using these roads was faced with the fact that his tires, which would deliver up to 30,000 miles on the older roads at lower speeds, were now requiring more regular maintenance and giving him no more mileage. He did not realize that vehicle weights and engine horsepower were being increased at significant rates.

Similar trends were occurring in truck tires, aircraft tires and off-highway tires.

This slide (Figure 1) illustrates the trend in sizing of off-highway tires over this period. The 47.00-51 tire is 11½ ft in diameter. Naturally, the larger tires were expected to carry proportionally greater loads with no sacrifice in operating speeds.

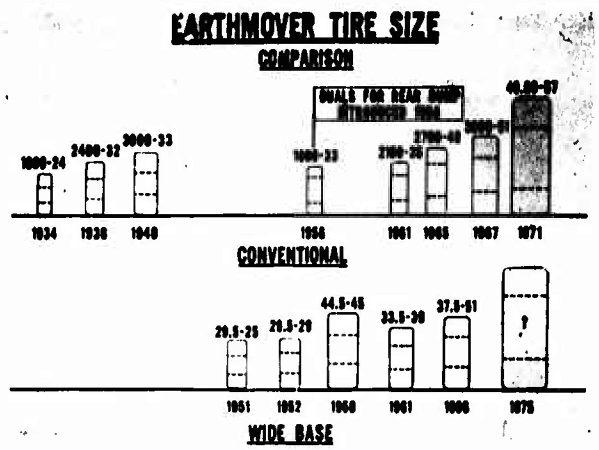

FIGURE 1

The new breed of tire consumer was getting harder to satisfy and some segments of the population were blaming tires for the increase in accidents brought about by the high-speed highway system. Consumer advocates, posing as spokesmen for the buying public, created a stir in the political arena and in 1966 the 89th Congress passed a law authorizing the Department of Transportation to establish tire performance standards for all tires used on public highways. The result was the MVSS109 standards for passenger tires with which we are all familiar.

Of course there were established military tire specifications and the heavy equipment industry had the economic wedge of "to the best performer goes the sales", a technique being forgotten by some individual tire consumers.

In addition to these factors, some states required tire inspection along with periodic vehicle inspection.

We at Goodyear had been concerned with improving the quality and performance of all our tires and continuing programs were underway to improve such performance parameters as traction, handling and overall tire durability.

In order for Goodyear to furnish tires to all types of customers for all possible service conditions we have had to invest considerable sums of money in test facilities (Figure 2) (Figure 3) and equipment. Long ago we found that destructive laboratory tests could be devised to evaluate tires in certain critical areas such as the bead or the ply tie-in or the ply turn-up areas, but there was no way to measure the treadwear or service durability of a tire except by running a vehicle in the same type service it would see in actual use. Of course, this required a fleet of vehicles from passenger cars through off-highway type (Figure 4) and place to run each. Testing facilities for both indoor and outdoor (Figure 5) destructive testing have resulted not only in considerable capital investment but also in a large annual operating expense.

At Goodyear the Development Department is generally responsible for designing and implementing new tire tests and evaluating the applicability of new techniques to tire testing. In the 1950s we began inspecting tires in the development process by X-ray and thru-transmission ultrasound.

By using X-ray techniques we were able to inspect tires for voids which may occur in manufacture, particles of foreign material, wild bead wires, uniformity of bead construction and uniformity of the height of the ply turn-up around the bead bundle.

FIGURE 2

FIGURE 4

FIGURE 3

FIGURE 5

Thru-transmission ultrasound was used to detect trapped air pockets and/or ply and tread separations. In fact, we deemed this inspection worthy of a field trial and installed a unit in one of our retread plants to inspect truck tires prior to retreading. Use of this system was discontinued for several reasons, notably the fact that alcohol was used as the couplant which caused problems with operators. Over a long term it did not seem ultrasonically inspected tires performed any more satisfactorily than uninspected ones.

However, a visual inspection with X-ray, coupled with the tire engineer's knowledge of what components he wanted in his tire and where he wanted them, demonstrated to us that in the development of a tire one of the most critical factors bearing on both road and lab wheel testing was the uniformity of components and the uniformity of assembly of the tire. In other words, once the tire designer was satisfied that the tire was built precisely as he wanted it then he could be assured that his test data were not unduly influenced by mechanical factors or mis-construction. As a consequence of this early development work our management decided that X-ray machines should become an integral part of quality assurance in each plant. Today X-ray equipment is found in all our domestic plants and a large proportion of our international plants as well (Figures 6, 7, 8).

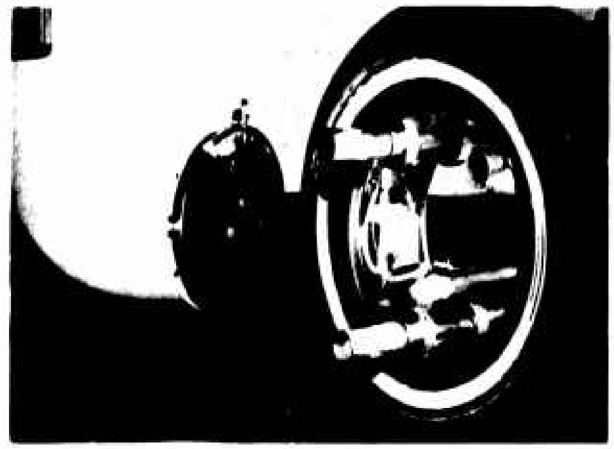

FIGURE 6

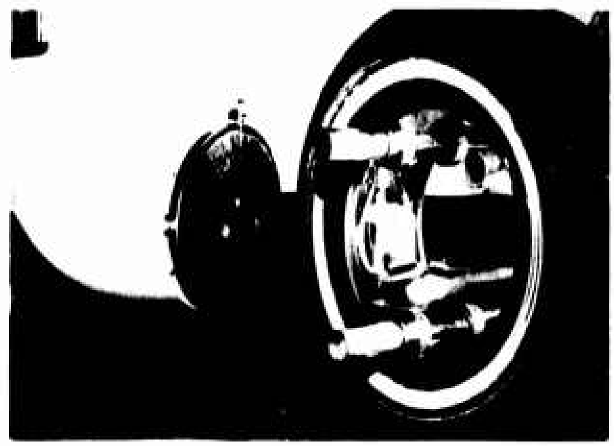

FIGURE 7

FIGURE 8

Our work with X-ray equipment has been related to uniformity of components, uniformity of the assembly of the tire, both green and cured, and finding blows and foreign materials in tires. We have not been able to isolate factors of construction which bear directly on treadwear or durability in service but we have found that uniformity of construction among tires of the same specification as revealed by X-ray analysis, does tend to be an indicator of performance because test data appears to group in a narrower range.

We have also determined that 100% X-ray inspection is both too slow and too costly for full production usage.

We believe that the X-ray operator who is interpreting the visual display is a vital part of the inspection system because his judgment, based on experience, is important to the classification of the tire. And finally, we are definitely committed to X-ray inspection of green and cured tires as part of both our tire development and production quality assurance programs.

In keeping with our responsibility for evaluating and applying new or different technology to tire testing we have investigated the potential of infrared sensing devices.

We usually categorize infrared devices into three types, slow response sensors, fast response sensors and scanners.

One example of a slow response device is produced by Barnes Engineering and is commonly referred to as a thermopile. This device has a relatively slow response to varying temperatures and thus is used to read average surface temperatures.

One application of the thermopile (Figure 9) has been by our Racing Division. The devices are mounted on a vehicle such as on a race car and tread surface temperature is monitored as the car circumnavigates a track. These data are telemetered to our mobile ground station where they are stored on magnetic tape for later analysis. (Figure 10)

A temperature profile (Figure 11) for the race course is valuable to the car suspension technician as well as the race tire designer and compounder.

An example of a fast response system is the Sensors, Inc. unit which measures the Δt of the rotating, loaded tire. Similar instrumentation is also available from Monsanto in a package especially tailored for a laboratory DOT type flywheel tester.

We have set up three heads, (Figure 12) one on each shoulder rib and one on the center rib of aircraft tires running at speeds up to 224 mph. Normal temperature variations were found to be about 20°F around the tire circumference. Small sharp peaks did not appear to be significant.

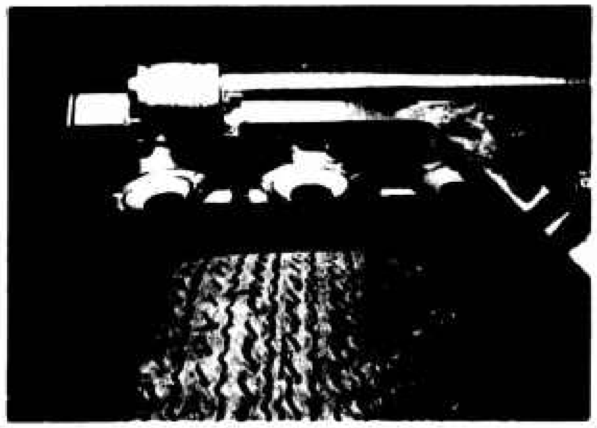

FIGURE 9

FIGURE 10

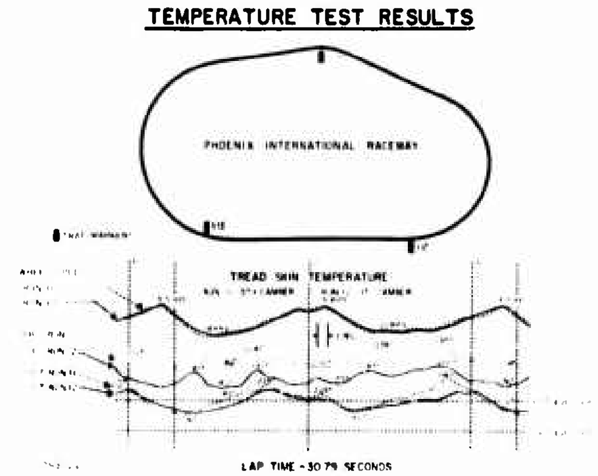

FIGURE 11

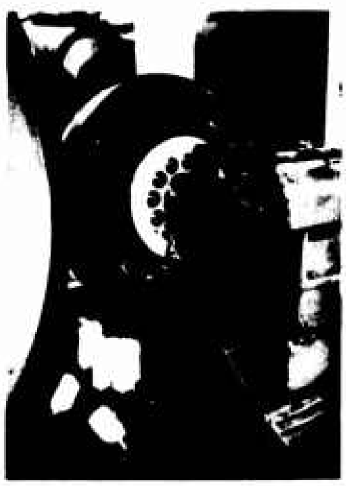

FIGURE 12

In one test on 46x16 aircraft tires a 4 oz balance patch was placed in the tire, a temperature profile generated, then the patch removed and the test repeated. With the patches removed the area at which they had been located ran 5° to 10°F hotter than when the patches were in the tires. Another test on 52x20.5-23 tires indicated the spot where the balance patch had been run hotter with the patch removed. This slide (Figure 13) shows a typical infrared trace of a tire with a void.

Both these tests showed that the light balance side of the tire was cooler than the heavy side. There are several possible causes for this but the exact reason is unknown. It could be due to a larger radius on one side of the tire as a result of a higher cord angle or it could be due to heavier gauge in the tread or carcass at the same radius, but neither of these explanations is precisely consistent with all the measurements of tire runout and thickness.

We have also noted that tread grooves run several degrees hotter than the ribs, probably because of greater flexing and bending in the areas with less structural rigidity.

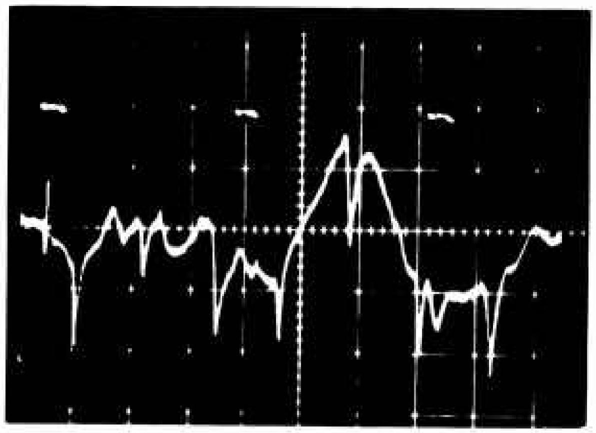

FIGURE 13

The differences between sensor indicated surface temperature and probe or internal tire temperature has been found to vary as much as 20%, depending on size and type of tire and the area of the tire being inspected. The bead area shows the largest differences. In our opinion, infrared monitoring of tires undergoing wheel tests if of value in instances where the test is designed to fail the tire by creating heat in localized areas. Infrared monitoring of lab testing is complicated by airflow in the vicinity of the tire and by the unknowns which may cause a spot on the tire to "flare up" to a high infrared peak then disappear, never to reappear nor to relate to the final test result in any way. An infrared system should ideally combine the characteristics of the thermopile and those of the focused fast time response instruments to provide both an average skin temperature and the variation in temperature around the tire.

In addition to the two types of sensors mentioned, we have observed operation of the AGA Thermovision/Comstock and Wescott System which scanned the stilled mirror image of a rotating tire. This system, using liquid nitrogen as a temperature reference, did make possible the measurement of both absolute and varying tire temperature. However, it had the disadvantage that mirrors were required at each test position and a rotating mirror had to be synchronized to the tire rotation. The mechanical complexity of the total system, in our opinion, made it unsuitable for our routine test lab use.

Our Development Department has made extensive use of the GCO AT12 laser holography system (Figure 14) to determine the size of voids within tires and their relationship, if any, to tire durability as measured by our tests. Holography has proven to be an effective means of finding voids, almost regardless of size. But we have found some disturbing evidence that indicates the presence of voids in new, i.e. not retreaded, tires has little bearing on durability. We have very strong evidence that a void which is built into a tire in the natural course of the building process has no relationship to a test failure. On the other hand, the same cannot be said for artifically induced separations where there is some foreign material such as polyethylene film.

FIGURE 14

In a test which we conducted to determine what happens as bias/belted passenger tires are run in service, we holographed tires prior to testing, then at various stages throughout the test sequence. The tires were loaded to 140% of T&RA 24 psi rating and inflated to 40 psi. The following holograms are typical of the findings. Notice the changes in the interference fringes as the test mileage increased from 0 to 4400 to 10,000 miles. (Figures 15, 16, 17)

Let me emphasize that this is a test by our Development Department and is of much greater severity than tires are subjected to in normal over-the-road service.

Our Aircraft Tire Engineering Department examined over 80 test tires prior to dynamic testing in one of their studies. They cut all tires with large abnormalities to determine the effectiveness of the method and to establish some holographic references. Those tires not cut were tested, either for an intentional failure or on a test where no failure was intended. They found some interesting facts, but the most significant finding of this entire study is in the summary.

> "Looking at only those tires run on tests where tire failure was not intended, the tires that appeared okay with the holograph had a 58% chance of failure while only 45% of the flawed tires failed."

So, while the laser holography technique can be a good indicator of apparent tire integrity, one must be careful or erroneous conclusions may be drawn.

However effective the holographic technique is, it suffers from two rather serious drawbacks; the preconditioning requirement and the fact that the film must be developed and analyzed. Preconditioning requires the tires be set with the beads spread apart for up to 20 minutes before making the hologram. Development of the film and analysis of the hologram, even on a production-type flow, requires the tires be held in the test area for at least 30 minutes. That requires a lot of storage space. Analysis of a hologram is dependent upon the conscientious nature of the person making the analysis. He must examine the hologram closely and cannot assume that anything he sees is "normal".

We have established a rating system of from 1 to 10 denoting the severity of holographic non-uniformity. The operator rates the tire based on his interpretation of the hologram and reports the severity and location to the designer.

FIGURE 15

FIGURE 16

FIGURE 17

The following examples (Figures 18a-b, 19a-b) of holographic ratings illustrate the rating system. The exposed cord cross sections are fiberglass.

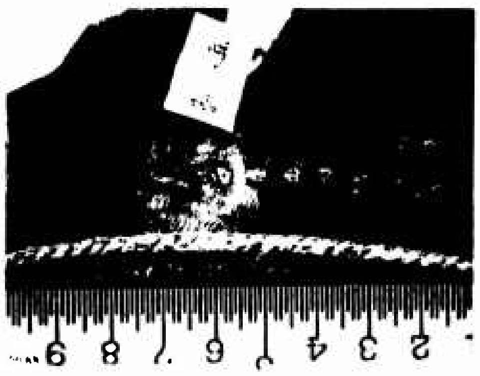

FIGURE 18a

FIGURE 18b

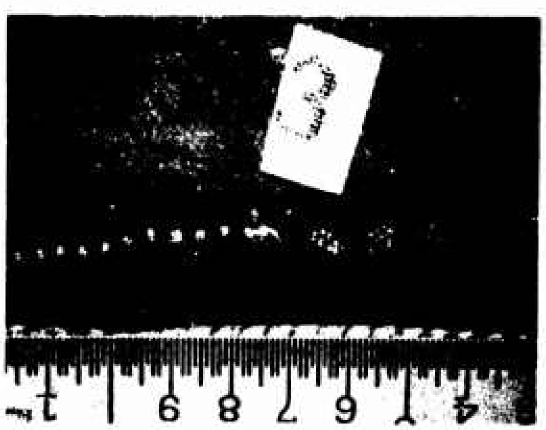

FIGURE 19a

FIGURE 19b

As mentioned earlier, about 23 years ago Goodyear used a thru-transmission ultrasonic system for inspecting truck tires prior to recapping and its use was discontinued.

More recently we have limited our ultrasonic testing to small contracts with independent investigators or instrument manufacturers attempting to successfully market tire test systems. Our international organization has had a contractural agreement with Automation-Sperry in Australia for evaluation of their air coupled thru-transmission system (Figure 20) which is designed primarily for aircraft tires. Our work with them has emphasized, but has not been limited to, aircraft tires.

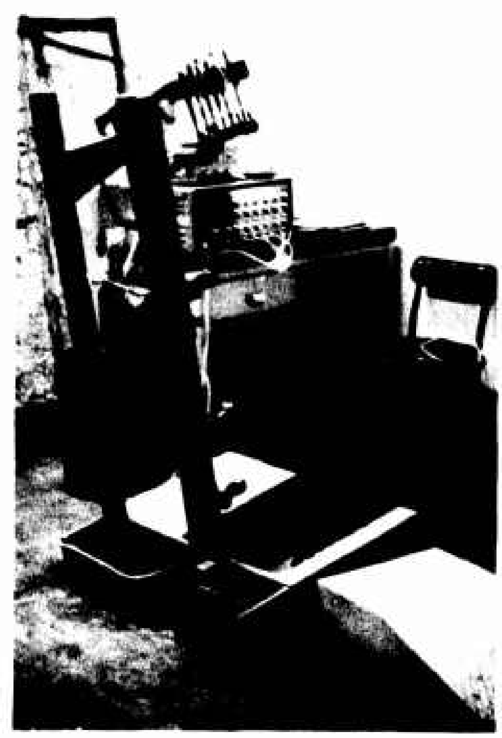

FIGURE 20

The findings in Australia tend to verify some similar work done for us by Automation Industries in Boulder several years ago. Smooth rib tread aircraft tires can be inspected easier and with greater confidence of success than can highly bladed passenger tires.

An interesting finding in Australia occurred when worn retread tires were inspected prior to application of another tread and found to have separations. Buffing to the former buff line revealed the separations. Such tires were subsequently retreaded and reinspected and found to be sound.

We have learned something of the response of tires to low frequency ultrasound from these contracts and have observed things which may be of academic interest. At present we do not believe thru-transmission ultrasound has the potential for development into a general purpose tire inspection tool although it may be quite useful for special applications.

Our work with pulse echo or reflectance ultrasound has also been limited primarily to outside investigators, but in our opinion pulse echo ultrasound probably holds the most promise for development into a viable tire inspection tool.

One of the most successful demonstrations we have seen of the capability of pulse echo ultrasound was by Gwynn McConnell of NADC. Several years ago we sent him five bias/belted polyester/fiberglass passenger tires which we had especially built with deliberately placed ply-to-ply or ply-to-tread separations of different sizes and with areas of weak bond. The separations were not made by inserting film in the tire but were to be as near natural as possible. We had inspected these tires and thought we knew what we had.

Gwynn McConnell inspected these tires blindly, i.e. with no prior knowledge of their construction. He was able to accurately describe and locate the built-in separations and also to locate and describe some smaller ¼"x¼" and ¼"x½" separations of which we had no knowledge.

We have followed the advancements in ultrasonic tire testing and have talked with instrument manufacturers but have not seen fulfillment of some of the claims even though we acknowledge the potential this discipline holds. One factor in this field appears to us to be extremely important, maybe more so than in any other field, that of operator interpretation. An unbiased open-minded person with scientific curiosity seems to us to be indispensable in interpreting ultrasonic responses from tires.

There is one area within the accepted definition of nondestructive testing where we have tried, with varying degrees of success, to examine tires or tire components. We refer to it generally as electromagnetics. In this broad category we include variable inductance devices, variable capacitance devices, eddy current devices, etc.

We have equipped our passenger tire retread plants with variable inductance transducer systems (Figure 21) to measure the thickness of the tire carcass after the buffing operation. This system is limited to comparatively small thicknesses but has enabled us to retread fiberglass belted tires without buffing into the belt. The operation of the system is simple enough that the retread laborer can use it with little instruction. This system is used as a process control and not to inspect outgoing finished products. However, the buff limits have been established by our Retread and Repair Development Department after extensive testing against the original DOT compliance standards for retreaded tires.

FIGURE 21

WHAT WE WOULD LIKE FROM NDT

Our assessment of the state-of-the-art of non-destructive testing of tires and other rubber products leads us to conclude that the two distinct areas of development and production impose different limitations on equipment which are not always clearly understood by those outside the rubber industry. Obviously, a development tool can be much simpler and inspection time greater than could be tolerated in production.

Data readout need not be complex in a development or research atmosphere. In fact, an unsophisticated analog recording can be extremely useful. Conversely, a piece of production equipment must be capable of faster inspection and use a simplified go-no-go type readout. Unless the development machine is capable of defining what must be interpreted on the production machine both are of little value. Our interest in non-destructive testing is not limited to finding possible flaws in cured tires. Our concern is elimination of them.

A knowledge of flaw propagation is basic to defining or isolating causes of premature tire failure. We are aware of little work having been done in defining tire failure mechanism. We believe significant advances in the state-of-the-art of non-destructive test technique and instrumentation are necessary to discriminate among the subtle variations which seemingly occur among, and within, tires.

We would like to inspect both green and cured tires (Figure 22) to determine tire geometry and construction uniformity. We would like to find microscopic porosity or variations in density at known locations and depths within the tire and their effect on performance.

INSPECTION OF GREEN AND CURED TIRES

- GEOMETRY
- POROSITY
- CORD
- THICKNESS
- FLAWS

FIGURE 22

We would like to identify weak bonds and cure variations within the same tire and among tires of similar type.

We would like to be able to differentiate among tire cords, e.g. polyester, nylon, aramid and steel, with sufficient resolution to detect the variation in count per inch. We would like to do these things on passenger, truck, aircraft and off-the-road tires where the sidewall gauge may range from .3 inch to 1.5 inch and tread thicknesses range from .5 inch to 8 or 10 inches.

We need a means of economically and accurately measuring thickness of large off-highway tires and a method for finding possible construction flaws in large as well as small tires.

Obviously this sounds like wishful thinking, especially if one expects a single instrument to perform such an array of functions. However, we are constantly being asked what we would like to see in the way of tire inspection equipment and these items do enumerate some of our areas of concern.

Figure 20 Courtesy of Automation-Sperry of Australia, Ltd.

QUESTIONS AND ANSWERS

Q: On holography, is that limited to mostly new tires, and is that at the San Angelo test track?
A: We have two units today, we have one in Akron and also one in San Angelo. This was the Akron unit, if we want to keep close track of tests we run it in Akron.
Q: Have you done any retread work?
A: Very little, but yes we have.
Q: Would you repeat please regarding that portion where you mentioned correlation of defects artifically induced or natural?
A: We have some very disturbing evidence that says that a "defect" or production flaw which is built into the tire naturally, that is occurs during the natural building process has little or no bearing on the durability or serviceability of the tire; whereas on the other hand, if a defect or separation is built in using a film such as polyethelene that most always results in a failure at that location. Does that answer your question?
Q: It would seem that you wouldn't have any problems.
A: That's an oversimplification. I think everyone in the tire business is aware of the problems or else we wouldn't be sitting here. But I would like to believe that we are able to keep them under control. But being able to do some of the things that we'd like to do would also assist us in eliminating some of the problems that we have.

WATER EFFECTS ON TIRE RETREADABILITY

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ABSTRACT

A study was made under U.S. Army TACOM contract of the ability of used military tires to absorb water from holes or cuts which have penetrated into the cord plies. It was felt that tires that might have moisture trapped in them after retreading or repairing, would be subjected to ply separations and shorter tire life. It was found that water can infuse into the ply structure in substantial quantities in certain types of tires. The extent of water infusion was measured by unique destructive and nondestructive techniques developed during this program. An inexpensive non-destructive approach was developed to permit a rapid, accurate evaluation of extent of water infusion by field personnel. An experimental study was made of potential procedures that could be used to dry the cord ply structure in an affected tire.

The objective of this paper is to describe the results of a TACOM program to define the retreadability of tires whose ply layers have been exposed to moisture intrusion (through injuries), to identify tools whereby maintenance personnel can measure the moisture intrusion extent and estimate the effects on retreadability, to suggest appropriate alterations to TM9-2610-200-34 (DS and GS Maintenance Manual on Pneumatic Tires) with regard to possible drying and handling procedures, and to thereby improve the reliability of retreaded military tires.

It was found that military tires are capable of absorbing moisture through injuries. Such moisture affected defects can cause disbonds during curing and premature failure during tire use. Nondestructive means were found to evaluate moisture. Drying and handling procedures were evaluated and recommendations made appropriate to a TM revision.

INTRODUCTION

Tire degradation caused by moisture related defects has been suspected by the Tank Automotive Command (TACOM) for some time. A small but nevertheless significant percentage of sudden tire failures has been felt to be caused by moisture entrapped in the cord ply structure. The mechanism of failure appears to be the fatigue extension of a region in which delamination or cord-to-rubber bond degradation has been induced by moisture presence. This region propagates under dynamic loading with attendant frictional heating and leads to failure when local stress concentrations exceed the tensile strength of the tire.

The moisture is usually absorbed through cuts and holes penetrating the ply structure, but we noted some instances in which moisture was absorbed through the interior lining into the first few inner plies of an otherwise intact tire. Thus, the absorption of moisture into cord plies is a possibility in any case where a nonoperational tire has been exposed to water. The occurrance of tires with this potential in the general military tire population is not accurately known at this time, but laboratory testing indicates that they could represent up to 15% of the population.

This program was undertaken to evaluate the rates of moisture absorption into cord ply areas, to develop a nondestructive measurement of moisture so absorbed, to relate moisture content to static mechanical properties such as tensile strength and to dynamic properties such as heat distribution, to study drying methods, and to consider changes in Army procedures related to tire retreading. All of these objectives were successfully completed. In fact, some fairly unexpected and important findings were made which may have substantial impact on tire maintenance procedures.

MOISTURE ABSORPTION

Evaluation of moisture absorption rates was accomplished using one destructive and three nondestructive techniques. The destructive method, undertaken to establish a correlation base for nondestructive methods used later, required immersing exposed ply sections in water doped with fluorescent dye (Figure 1). The rates of water diffusion and water-dye diffusion had been previously found to be essentially equal in isolated cords. Thus, when each tire section was removed from the dye and sliced into one-half inch strips (Figure 2), the extent of dye penetration revealed by observation under ultraviolet illumination was the measure of moisture penetration.

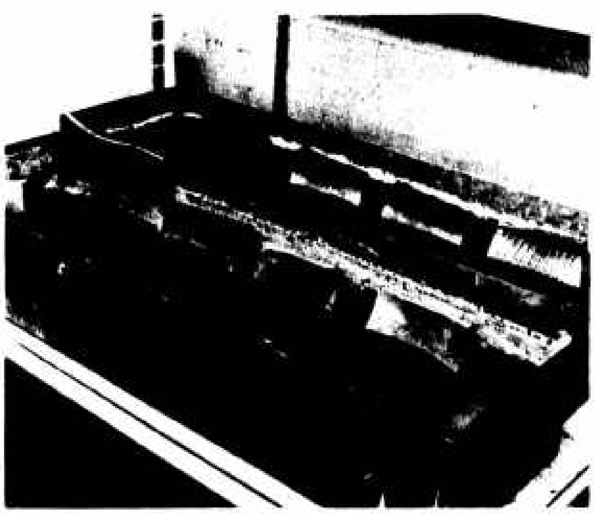


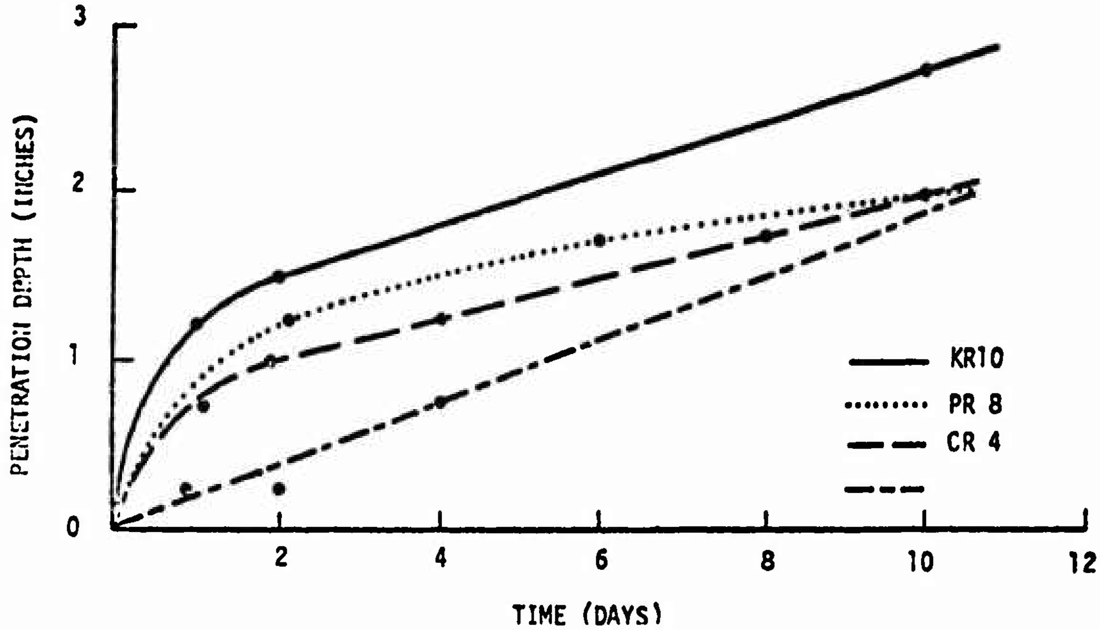
FIGURE 1
TIRE SECTIONS BEING SOAKED

Polyester, fiberglass, and most nylon corded tires did not show any observable dye absorption. However, rayon and about 10% of the nylon corded tires did show absorption (Figure 3). Most of the absorption activity had taken place by the end of the second day of exposure, but a steady infusion rate could continue for weeks.

FIGURE 2
EXAMPLE OF TIRE SLICES

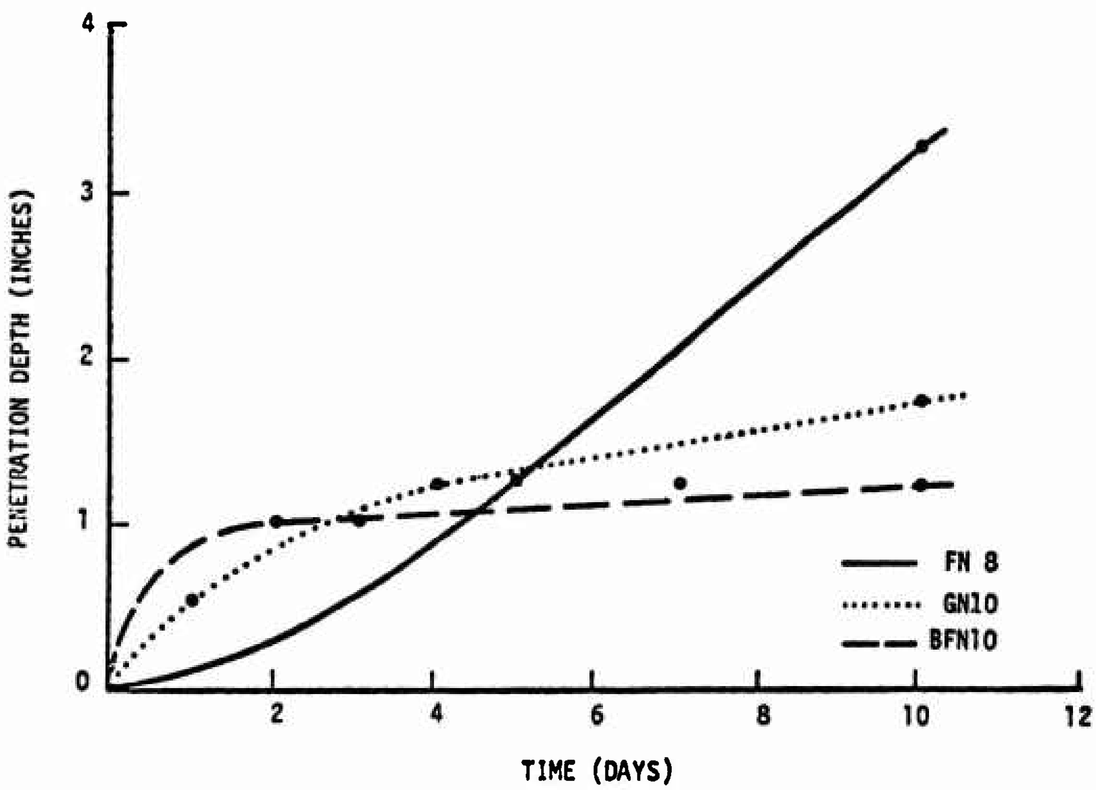
Nondestructive methods of evaluating mositure absorption rates were the use of electrical conductivity probes, weight measurements, and radiography using lead salts. The procedure using radiography was preceeded by an immersion of tire sections for varying times in a saturated lead acetate solution. The resultant pictures show agreement of lead penetration rate with the dye evaluation of absorption rate, and they also demonstrate (Figure 4) that absorption takes place principally along the cords. This radiograph shows how lead acetate, carried by water, is restricted to those cords having access to the physically damaged region.

FIGURE 4
RADIOGRAPH SHOWING WATER PENETRATION IN CORDS



(a)

RAYON CORDED TIRES



(b)

NYLON CORDED TIRES

FIGURE 3
WATER PENETRATION DEPTH IN TIRES VS. IMMERSION TIME

Weight analysis was used primarily for comparison of drying methods discussed below, but additional studies were done on absorption rates. Figure 5 shows agreement with the rates found by above methods, but it also shows that tires in which no dye or lead acetate could be detected also absorbed moisture, albeit at a much slower rate. This slow rate continued for more than a month, resulting in infusion depths of one inch or more. Therefore, given enough exposure time, any nylon or rayon corded tire can absorb potentially damaging amounts of moisture.

The nondestructive method eventually adopted as our recommended production line inspection technique was the use of an electrical conductivity meter equipped with needle probes (Figure 6). The needles, separated by one-half inch, are inserted into the plies of the inspected tire. Readings over a specified threshold indicate moisture presence. Use of this method to plot infusion rates yielded agreement with previous methods.

FIGURE 6
WATER PENETRATION METER

Because this meter is extremely sensitive to the low resistance paths of water in the cords, care must be exercised in inspecting for water around small puncture defects. Unless the needles are aligned along cord lines intersecting the puncture, as illustrated by the radiograph (Figure 4), water presence could be missed due to high rubber-dry cord resistance reducing signal to the meter. The possibility also exists that variations in the carbon content of tire rubber could alter the resistance of the dry tire, thus varying the moisture indication threshold. Preliminary investigation suggests that this occurs rarely and that it can be compensated for by prior knowledge of the carbon content. With these two cautions, the conductivity meter provides a portable, simple, reliable, and rugged nondestructive device for detection of moisture in tires.

PERFORMANCE ALTERATION

The suspicion that moisture can degrade the service life of a tire was justified by our findings during tests of structural integrity. The life of a tire is the time it can safely maintain its load-bearing strength. Since tire cords are the load-bearing elements, tire life is the time the cords can maintain their strength. The literature of textile engineering indicates that rayon and nylon, the main cord materials used in Army tires, absorb water readily and lose cord strength in doing so. Rayon, being a regenerated cellulose, absorbs very readily and can lose 40% of its dry strength while nylon, a polyamide, absorbs water less readily and can lose 15% of its dry strength.

We obtained similar results in tensile tests of cords stripped from tires, (Figure 7). Further tests on ply section strips also showed (Figure 8) loss of strength with wetting.

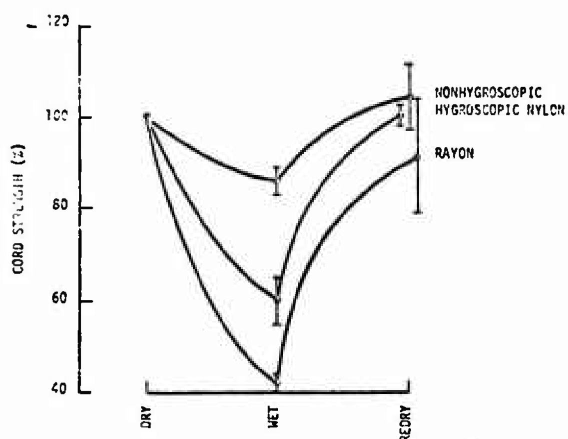
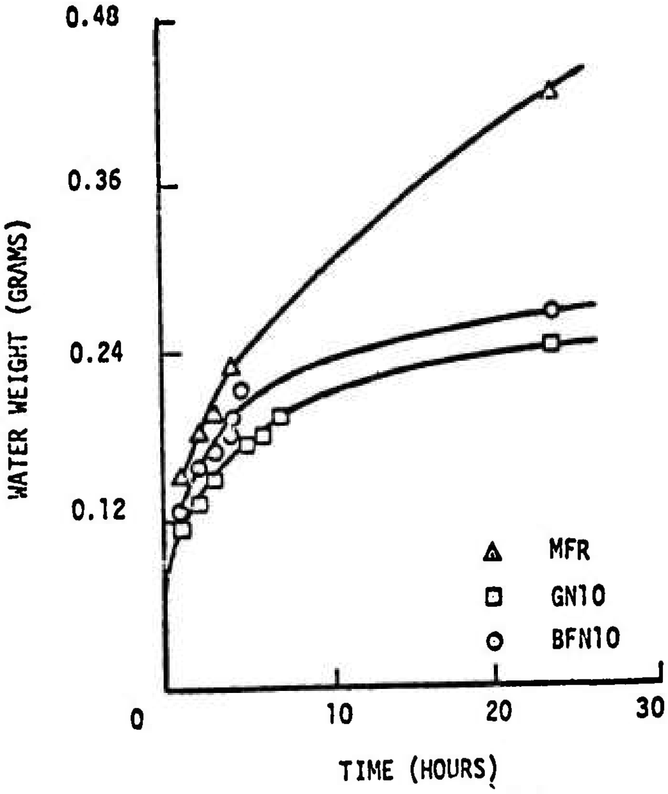
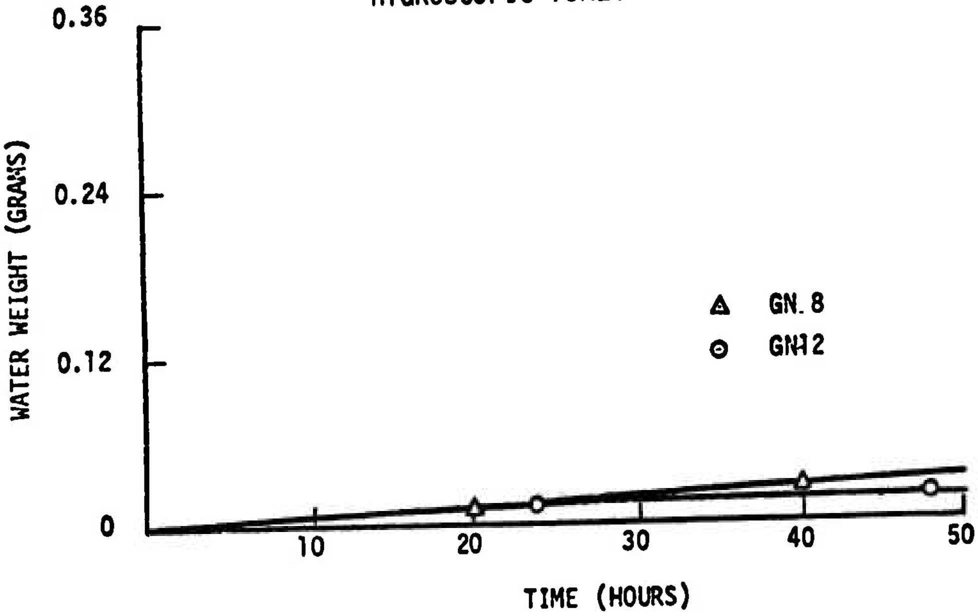


FIGURE 7
EFFECT OF WATER ON AVERAGE CORD TENSILE STRENGTH



(a)

HYGROSCOPIC TIRES



(b)

NONHYGROSCOPIC TIRES

FIGURE 5
WATER WEIGHT IN TIRES VS. IMMERSION TIME

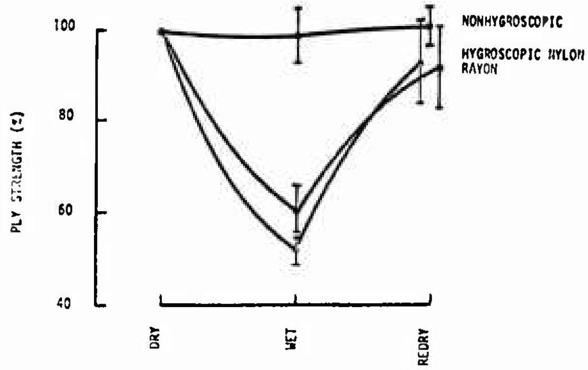


FIGURE 8
EFFECT OF WATER ON AVERAGE PLY TENSILE STRENGTH

In addition to strength degradation, moisture infusion can rupture an operating tire by steam generation. At the present time there is still uncertainty whether a properly inflated tire, operating under road conditions in a moderate environment, generates enough heat to raise its internal temperature above that of boiling water. It is known that operation in high temperature environments, excessive braking or acceleration, or improper loading can cause the tire to exceed this point rapidly. We studied two types of heating, a slow rate of heat delivery to infused water by convection and conduction (oven immersion), and a rapid rate of heat delivery by radiation (microwave heating). Each produced a characteristic type of steam-induced damage.

Slow heating did not produce massive delamination, but apparently had the potential to pit the cord-rubber bond as shown by the appearance of craters in a wall of sealing epoxy used to encapsulate a "wet" edge of a tire section which had been soaked in water. Rapid heating caused obvious delamination (Figure 9), and further tests showed that these ruptures occurred at temperatures not far above that of water vaporization.

DRYING

Considering the extreme environments under which military tires must be expected to operate reliably and safely, it is apparent that water infusion can be a matter of great importance. Having found that a significant percentage of the tire population is capable, when sufficiently damaged, of absorbing water, and having explored a nondestructive means of inspecting for that water presence, we next studied methods of drying tires to recover their post-repair reliability.

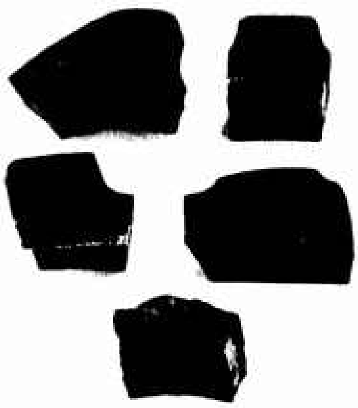


FIGURE 9
HEAT-CREATED DELAMINATIONS

The methods examined were application of microwave radiation, exposure to vacuum, and air drying at different temperatures. Figure 10 shows percentage water weight loss from tire sections exposed to the different techniques vs. time of exposure. Microwave application achieves the best initial drying rate and, except for 300°F air drying, would be the best method if it were not limited by the necessity to cool the tire after short periods of heating. Air drying at 300°F is the best method in terms of water weight loss per exposure time. However, this method, along with the next two most effective (vacuum and 180°F air drying), requires specially constructed, expensive, and energy consuming facilities. When we found that no method (except 300°F air drying) could remove moisture deeper than one-half inch from the defect, and that this depth could be dried at 68°F within 96 hours, the use of the more elaborate methods clearly became uneconomical. We, therefore, concluded that tires with moisture extending beyond one-half inch from a presently acceptable defect should be treated as condition code H (not economically repairable), and those which show lesser moisture extent should be set aside in a sheltered area at room temperature to dry.

In recommending alterations in the army repair and retread procedures, we were guided by the philosophy that the potentially damaging presence of moisture in a tire and its limited capability of being removed required its being

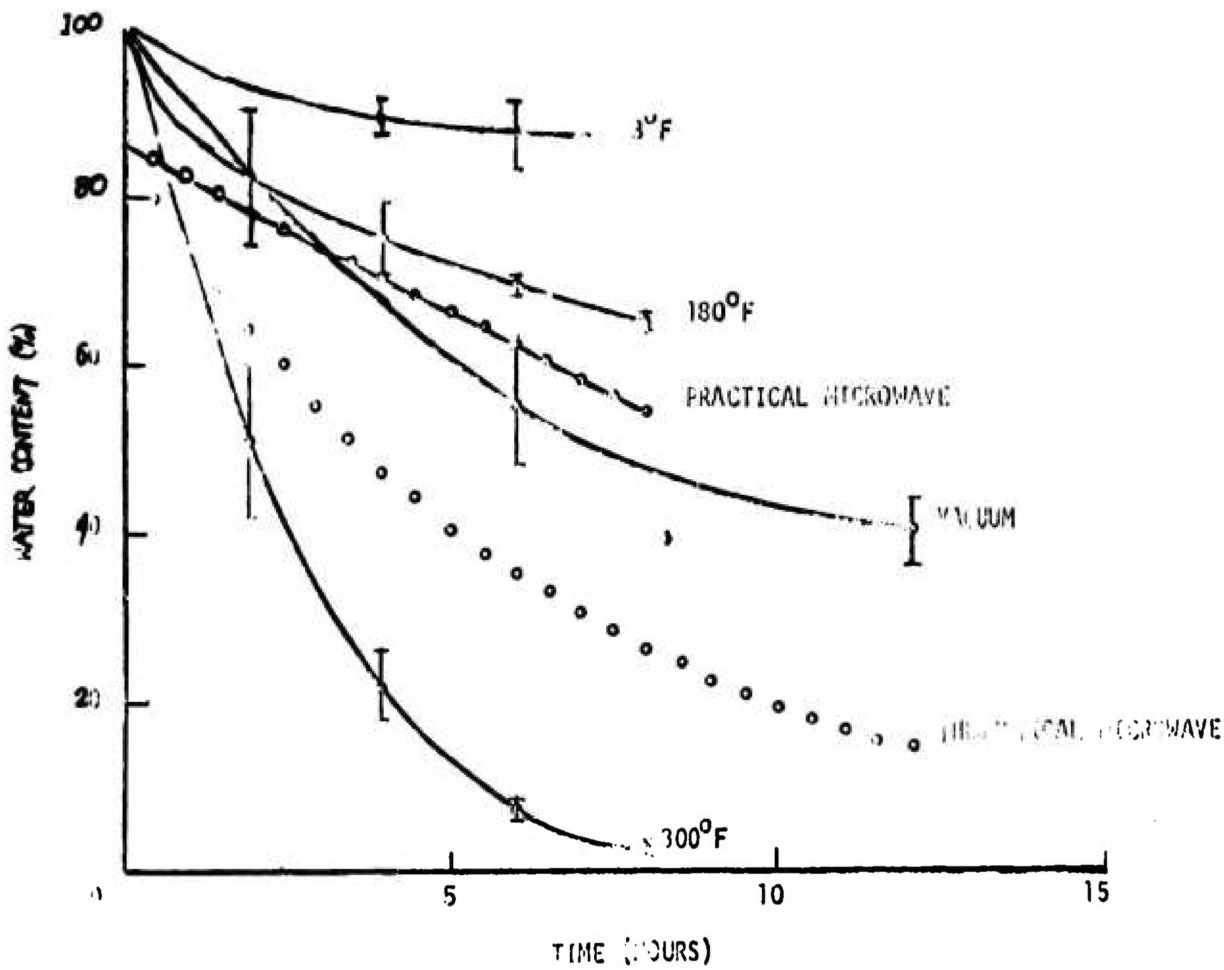


FIGURE 10
COMPARISON OF DRYING METHODS

regarded as a defect in the same sense as a cut or a puncture. Thus, where the present procedures dictate a maximum limit on the size of defects, our recommendation sets the same limit on the extent of water-affected area. Where present procedures prescribe a course of repair of a defect, we recommend the same course for the defect plus four days' drying for any water affected area within one-half inch of the limit of that repair. It is also clear that some consideration should be given to provide shelter for tires awaiting retread or repair, especially in wet climates to avoid prolonged exposure to water.

CONCLUSIONS AND RECOMMENDATIONS

1. All tested rayon and a significant minority of nylon corded tires were capable of absorbing substantial amounts of water from cuts and holes.

2. Moisture inspection of ply-damaged tires should be instituted as part of the retread or repair inspection procedure.

3. A moisture gage acting on the principle of conductivity measurement can be used to perform this inspection. An FSN should be assigned to, and specifications written for this gage.

4. Tires with a moisture penetration area larger than the currently acceptable physical damage extent should be rejected.

5. Drying rooms are not recommended. Tires should be surface dried and inspected for cuts. Cut tires should be stored in a dry area and inspected for water content at the termination of this storage. Those tires with a moisture penetration area less than rejectable size should be subjected to a combination of skiving and drying at room temperature to remove water affected areas, as drying of extensive moisture is not a practical possibility.

6. The minimum amount of moisture required for ply separation at high heat loads can be found in hygro-

scopic tires which have plies exposed to water for less than twenty-four hours.

7. Changes should be made to the Pneumatic Tire Maintenance Manual (TM9-2610-200-34), pending cost impact studies.

8. A field survey to find the distribution of moisture-affected tire injuries is necessary to determine the cost impact of suggested maintenance manual modifications.

9. Further experimental work should be performed to clarify the dependence of tire safety and maintainability on the presence of moisture related defects.

QUESTIONS AND ANSWERS

Q: In your chart where you showed length of time to dry out moisture, how soon do you have to process that tire before it starts picking up moisture?
A: Well we found at room temperature just, a normal room temperature, it will not absorb moisture. It takes liquid-water in a liquid state, to get it to do it. So if you keep it in like a covered area you will find that you don't have to worry about it. It is recommended that once you start considering handling a tire for retreading that you store it someplace that's dry. It's dry forever unless you physically soak it in water.
Q: It won't pick up moisture from the air?
A: No, it doesn't seem to do that.
Q: Your statement bothers me, that you do not recommend the use of drying rooms. I didn't catch your reason. In the view of the fact that Mil-Spec 7726 Tri-Service Spec. for aircraft tires says you must go through the drying room.
A: Well, we found from our experiment, that a drying room is basically setting the tire in 180°, in that range, and if the tire is wet, that doesn't do anything for it. Maybe drys 1/2" or 3/4" moisture. If you have those facilities available, perhaps we may have saved as many tires as possible or get that 1/2 or 3/4" but a lot of people do not have facilities like that available and I have a feeling that, – well maybe not in the aircraft industry, – but in most of our cases it is not too closely adhered to.
Q: Is there any indication that the rubber itself is hydroscopic?
A: We found several cases where the tread would actually soak up moisture, but that actually didn't happen very often. I presume that is related to porous tread and non-porous. Well, we didn't completely test the sections as they were pulled out to find out what tread did absorb water. We sectioned 20 or 30 tires.
Q: Could you also tell me about the conductivity of tread rubber? Is that variation around a tire or between tires?
A: It's from tire to tire. It's fairly consistent on a given tire. Well there's a difference between the tread and say the rubber around the inner liner.
Q: Did you find any relationship between the amount of moisture that any single kind of fiber will pick up?
A: Given the class of tires that we are dealing with, they are very nonuniform. In other words we have tires built in 1952 and some in 1963, – and we have tires from Goodyear and Firestone, – and we can't see any amount of consistency except through age. I'm not certain that it is a manufacturing thing – at least not an obvious manufacturing fault.
Q: What percent casings do you think with the mentioned drying methods could be made suitable for retreading?
A: Well, again, we haven't gone out and conducted a general survey on doing this. Well, obviously your rejection rate is going to go up because you'll be rejecting in a category that's not covered now – you're maintaining all the rejection criteria that you have now and you're adding another one to it. The question of how frequently tires are filled with moisture in the field is unknown right now. We purposely soaked these tires. We have a couple of instances reported where one of our fellows went out and just at random tried it out on a couple of tires that they found at Army retread centers, and they found one right away that had moisture around an injury. And a few of the men at TACOM have taken the thing to some of the Army bases and examined cuts and have found moisture around them. Particularly as I recall, there were two instances at Fort Knox where they found cuts in passenger tires with moisture around the failure. Whether it got there before or after we don't know right now. That's kind of an interesting aspect that we'll talk more about tomorrow because it's tied together with a much more interesting phenomenon.
Q: You say that in the cases where you measured moisture penetration that you soaked the tires in the solution for maybe hours or maybe days, – but in practical cases this may not be true at all – you may only get a very small amount of moisture.
A: We were trying to form a "worst case", – and we did it on purpose, – then we were going to back off to a practical level. That is why we are conducting the survey, – we know that moisture will collect around cuts and we want to determine what kind of an impact this will have on the Army retreading program.

A RADIOACTIVE TRACER METHOD FOR THE EVALUATION OF AIRCRAFT TIRES QUALITY BEFORE RETREADING

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ABSTRACT

A new non destructive radioactive tracer technique has been developed for the evaluation of the quality of aircraft tires before each retreading. This method derives from the well known needle-test. Its goal is to evaluate the global fatigue of the tire and to detect local defects of the internal structure, such as unbondings between tread and carcass or between the plies, and also local increases of internal porosity.

It presents no danger of degradation of the quality of the tire itself and no risk of contamination or irradiation for the staff who carries out the tests or uses the tires afterwards.

The paper describes the principle of the method, the control procedure and the apparatus. Some typical results are discussed.

Such a method permits to define quantitative criteria of acceptance or rejection for each type of tires in function of their number of landings and their number of retreadings.

INTRODUCTION

The method which will be presented is a non destructive method. Its goal is to evaluate the wear characteristics of aircraft tires before retreading in function of their number of landings and number of retreadings.

This method derives from the well known air needle-test. It is based on the ability of a gas to diffuse along the plies of the tire, on between the plies.

It permits to evaluate the adhesion between tread and carcass and between the plies of the carcass itself.

It presents no danger of degradation of the quality of the tire itself and no risk of contamination or irradiation for the staff who carries out the tests and for the people who use the tires afterwards.

PRINCIPLE OF THE METHOD

The aim of the method which has been patented is to determine before retreading, if an aircraft tire shows or no any significant local defects in the adhesion between tread and carcass and between the plies of the carcass itself, and so to make sure if the tire is worth being retreaded.

Such defects occur mainly in the areas of maximum fatigue as shown in Figure 1.

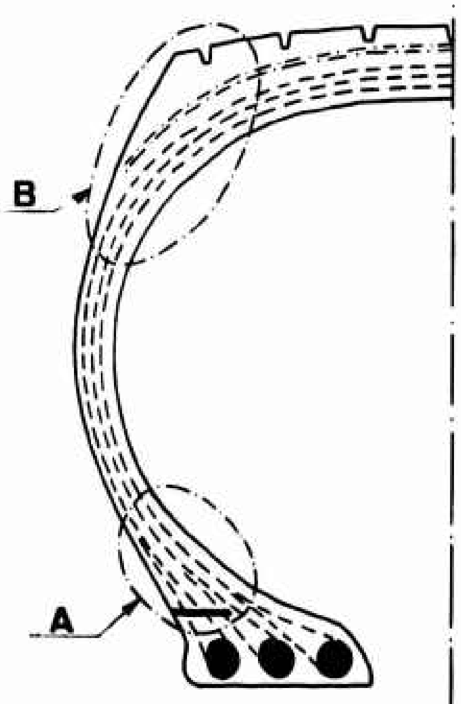

FIGURE 1
TYPICAL SHAPE OF A TUBELESS AIRCRAFT TIRE (A&B ARE THE AREAS OF MAXIMUM FATIGUE)

To solve this problem, we have injected, under pressure, with a needle through holes located in the area of the vent-holes, a gas tagged with a radioactive gas which emits soft γ rays.

Simultaneously during the injection, on a point diametrically opposite to the point of injection we measure the increasing of the count-rate. Afterwards, by scanning with collimated probes, we record the distribution of radioactivity along various profiles and this permits to detect areas of unusual storage of the radioactivity inside the tire.

Such areas are correlated with the local defects to be found.

EXPERIMENTAL DEVICE

Tracer Gas

The gas to be used is a mixture of nitrogen and xenon-133. This radioisotope is a γ emitter (81 keV - 37% with a short half-life* (5.27 days).

It is delivered in sealed glass ampoules.

The low energy of the γ rays, the short biological half-life of the xenon-133 and the chemical neutrality of nitrogen and xenon towards the materials of the tire are the three main important advantages of this choice.

Injection Device

The scheme of the experimental device is shown on Figure 2.

It comprises:

1. A nitrogen tank equipped with a pressure-reducer and a manometer.
2. A mixing unit with a pneumatic hammer in which the xenon ampoule is introduced and broken.
3. A tank of tracer gas (nitrogen + xenon-133) which can contain about 3 liters of gas under a maximum pressure of 8 Atmospheres.
4. 1 or 2 needles.

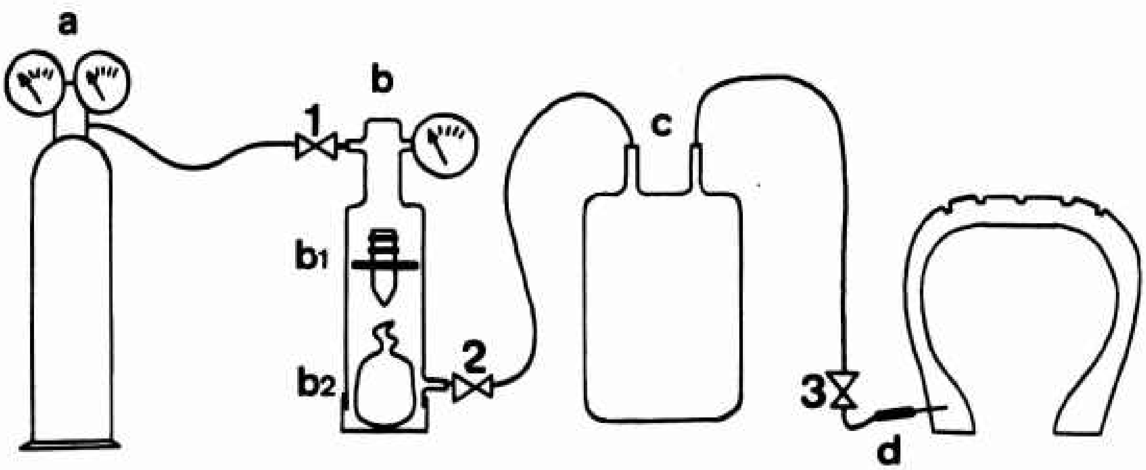

FIGURE 2
INJECTION DEVICE

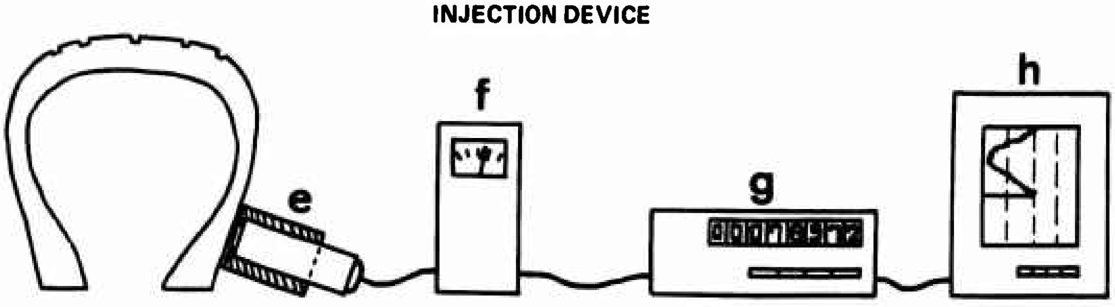

FIGURE 3
DETECTION DEVICE

* The half-life of a radioisotope is the time after which the initial activity is divided by a factor of 2.

Injection – Detection Frame

The tire to be controlled is set on a frame which permits its rotation around a horizontal axis.

On this frame the needles and the probes can be fastened perpendicularly to the external tire surface.

Detection – Device

Such a device is shown on Figure 3. It comprises:

1. Scintillation probes equipped with collimators
2. Ratemeters
3. Scalers with pre-time and/or pre-count functions
4. Recorders

Operating Procedure

At first valve 1 is closed. The pressure of the nitrogen is to be adjusted (for instance at 8 Atm). Then the xenon ampoule is introduced in the mixing unit. The valves 2 and 3 are closed. The valve 1 is opened. The ampoule is broken. The valve 2 is opened; when the pressure has reached again 8 Atm, valve 1 is shut. Then one has at one's disposal about 3 liters of useful tracer gas.

The needle is introduced into the tire, in the vent-holes area. The valve 3 is opened.

The injection time is about 1 to 5 minutes for a mean used 46 x 16/30 PR or 49 x 17/28 PR type tire.

During this time, one records the count-rate on a point diametrically opposite to the injection point.

After such a time the needle is disunited from the tire.

The scanning can be achieved by rotation of the wire and recording with one or more probes.

TESTS BEING CARRIED ON

We are now carrying on a lot of experiments in close cooperation with Air-France. We have settled a program of systematic tests on various types of tires which have undergone different numbers of landings and different numbers of retreadings. For instance, during the first half of 1974 we have tested a sample of tires used on civil jet–airliners, of four different types (49 x 17/28 PR, 46 x 16/30 PR, 39 x 13/16 PR and 35 x 9.00–17/14 PR), coming from two different manufacturers and three different retreaders. Furthermore the sample included new tires up to R10 tires.

RESULTS

Increase of Count-Rate on a Point Diametrically Opposite to the Injection Point, During the Injection

On new tires there is actually no significant increase, even after more than 30 minutes of injection at 8 Atmospheres, using a mixture of some millicuries up to seventy millicuries of xenon-133 in 3 liters of nitrogen. The count-rate remains at the level of the natural background which is about 15 to 35 counts per second with the device which was used.

On used tires the slope(s) of the count-rate curve may be equal to zero, or slow or even high. For instance, in the same population of 46 x 16/30 PR tires (R04) used in similar conditions, the curves are given by Figure 4. This figure shows that for a majority of these tires, there is no increase of the count-rate (s = 0) after 10 minutes of injection. But for some of them the count-rate reaches some times 100 counts per second above the background after 5 minutes of injection.

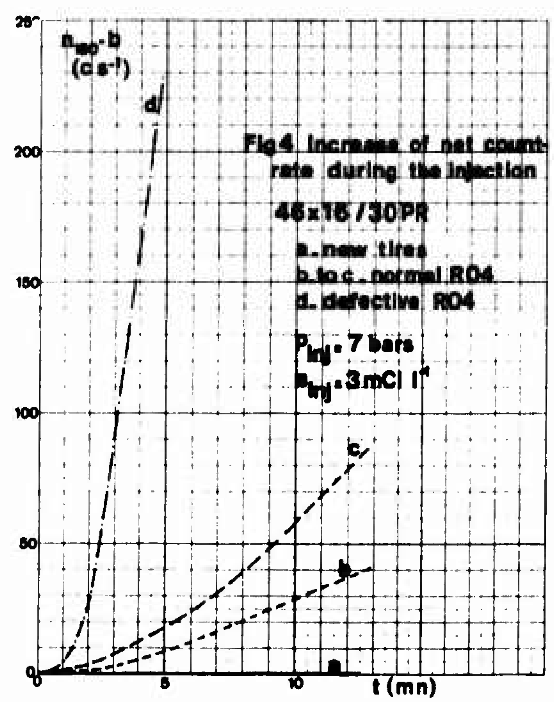

FIGURE 4
INCREASE OF NET COUNT-RATE DURING THE INJECTION

In the same population of tires, but with different numbers of retreading one can observe that the mean slope of these curves is increasing with the number of retreadings.

Moreover, it seems that when a particular tire of a given population has a slope clearly bigger than the mean slope of the population, this tire generally presents one or more important local defects.

Scanning of the Count-Rate Around the Tires

For a new tire there is no diffusion of the tracer gas along the plies or between them. The "gas storage capacity" of the tire is nearly equal to zero.

So in polar coordinates the activity is maximum just over the injection point and is equal to zero at some degrees of this point.

For a tire which is a little used and which presents no significant local defect it exists an internal global porosity and then the repartition curve of the activity looks like curve I (Figure 5). The ratio between the count-rate at 180° from the injection point (R_{MIN}) and the one over the injection point (R_{MAX}) could represent the global wear of the tire.

$$\text{So } \tau_G = \frac{R_{MIN}}{R_{MAX}} = 0 \text{ for a new tire}$$

$$\tau_G = \frac{R_{MIN}}{R_{MAX}} \nearrow 1 \text{ for a tire "completely" worn}$$

Thus the curve II is a characteristic of a tire more worn than the tire of the Curve I.

In the experimental conditions above mentioned, R_{MAX} can be reached 500 to 5000 counts per second above the background.

Generally one can observe that when the slope(s) defined in Chapter 4 is low, τ_G is small (for instance 10^{-3} to 10^{-2}), and when the slope(s) is high, τ_G is bigger (for instance 5×10^{-2} to 5×10^{-1}). These two parameters seem to be correlated.

The curve III is a curve of a tire which has the same global porosity (or fatigue) index τ_G as the one of the curve II, but it presents 2 locals defects.

We can so define a local index, τ_D, which will be the ratio between the true count-rate R_D at the defect point and the virtual count-rate R'_D which should be found at the same point on a tire with the same global wear degree and no local defect.

$$\text{So } \tau_D = \frac{R_D}{R'_D}$$ could represent the importance of such a local defect.

Figure 6 shows real scans of 4 profiles of a 46 x 16/30 PR (R04) tire showing no defect.

Figure 7 shows real scans of the same 4 profiles of a 49 x 17/28 PR (R02) tire showing an important defect which has been identified by destructive means (unbounding between plies).

Safety Considerations

With the experimental device an activity of about 10 mCi to 20 mCi permits to make two simultaneous injections (one on each flank at the same angular position) on a series of 10 to 15 tires.

This device was rather rough; sometimes there was some loss of activity. Sometimes the obtained count-rate was too high (>15000 counts per second). So we may say that in any case less than 1 mCi is needed to control one tire.

Furthermore, after the end of the injection the distribution curve of the activity inside the tire remain very stable. On a period of about one month, we observe that the leak-rate is nearly constant and equal to about two percent of the remaining activity per day.

So this permits to make the scan some hours or even some days after the injection (the resolving power of the method will of course be smaller). This is indeed very convenient.

And if one wants to store the tires, the activity remaining inside will become rapidly low (<0.1 mCi after 15 days; <0.01 Ci after 30 days) if the activity injected were equal to 1 mCi per tire.

If one does not prefer to store the "active" tires one can "wash" the tires with a nitrogen injection at a pressure slightly higher than the injection pressure.

These remarks will greatly simplify the safety and regulation problems which one will have to solve.

FIRST CONCLUSIONS – INDUSTRIAL GOAL

These results are hopeful. We do think that an industrial NDT procedure using this principle will be established and that the appropriate machine will be developed and made commercially available.

We are now carrying on a lot of tests and we shall make systematic correlations with destructive examinations of tires presenting various distribution curves with and without supposed defects.

We shall also make critical comparisons with other NDT methods like air needle-test, ultrasonics and holography.

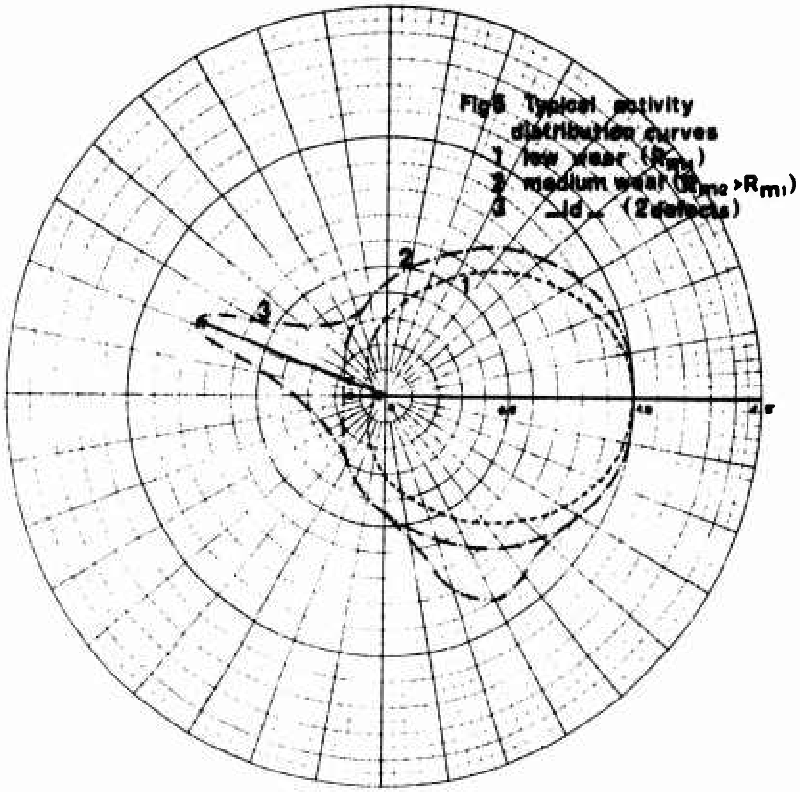

FIGURE 5
TYPICAL ACTIVITY DISTRIBUTION CURVES

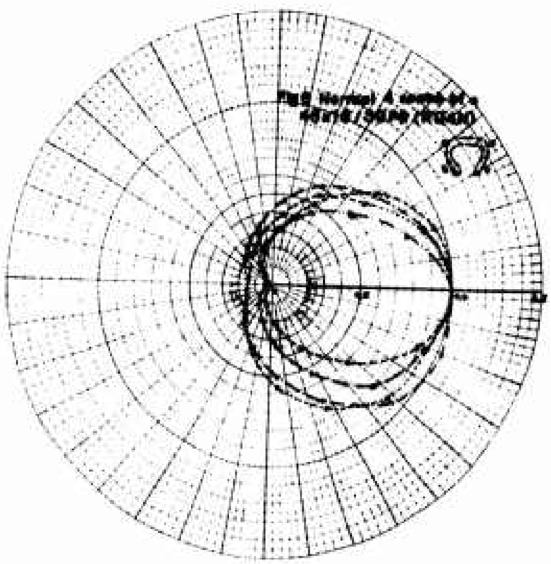

FIGURE 6
NORMAL 4 SCANS OF A 46 X 16/30 PR (R04N)

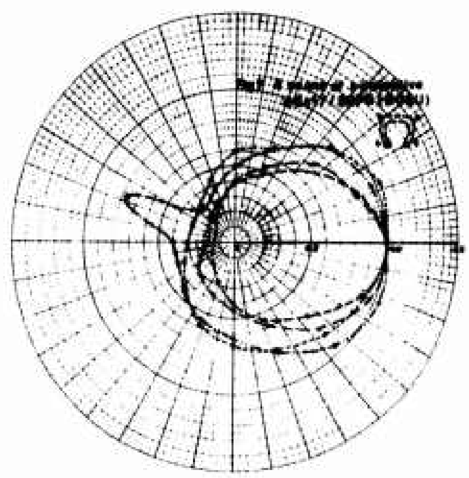

FIGURE 7
4 SCANS OF A DEFECTIVE 49 X 17/28 PR (R02U)

This will ensure us:

1. To set an exact characterization of each kind of defects detected

2. To define the minimum size of defects that the method is able to detect

3. To define standard count-rate increase curves during injection and standard distribution curves for each type of tire after different numbers of landings and different numbers of retreadings

4. To fix the minimum quantity of radioactive gas to be used (in any case less than 1 mCi per tire)

5. To optimize the injection (and especially to find the minimum useful pressure) and the detection devices

6. To solve any regulation and safety problems which could occur.

The goal is to realize a test machine as automatic as possible, with go/no-go acceptance criteria, but giving in any case a recorded document to the controller.

Such a machine will be able to test 100 tires a day.

But yet it appears clearly that this radioactive tracer method must permit a economic non destructive evaluation of the quality of aircrafts tires and will be a useful tool to improve the security of air transport.

QUESTIONS AND ANSWERS

Q: You have injections at one point only?
A: Yes. We make injections at one point only. The distribution curve around the tire is so different from one side to the other side, – that if you have a big defect on one flank, and this side is the injection flank, you have a kind of shadow on the other side. So we found that it is preferable to make two simultaneous injections at the same angular positions and with the same activity distributions, so you minimize the shadow effect from one side to the other, – and reciprocally.
Q: What happens if the failure area is right near the injection point?
A: That is a question that we are now addressing experimentally to find a good answer. I think the distribution curve will be quite different from the normal curve. The local gradient, I think, will be too high and when you look at the curve you will be forced to say that you are injecting on a defect. We want to get statistics to prove this answer.
Q: How many m.r. of radiation will you pick up, – say at one meter within an hour after the injection?
A: As I mentioned, we allow 0.1 millicurie during the experiments. The readout of the gamma meter will show a low gamma rate, – 87 keV, – and there is only one-third of photon disintegration so the dosage at the contact of the tire is less than 0.1 millirem per hour. So the dosage is less to the person making the experiment than normal personal doses in doing X-ray or gamma radiography.
Q: In your Figure 7 you have a very erratic curve. You may have covered this, – but was the tire then tested to authenticate whether there was an irregularity or a defect in that particular test that you had?
A: Yes, – we made cuts of the tire and made sure that where we thought there was no defect there were none. Also, we confirmed that there was a defect – a bulge – between the rubber and the cord and another separation within the body of the tire measuring about 2-inches long and one-half inch in width. And, in fact, when we made this test of a tire – it was during a demonstration for Air France, British Airways, Swiss Air and some other companies, – Air France had picked this one tire from a stack that they felt had defects. When we made the complete scan then cut the tire the anomalies we found answered the question.
Q: When the tires have been examined by injection, can they be put back into service and retreaded further?
A: Yes. As I told you, this is difficult to answer because I am not sure of safety regulations in this country. But in France a firm answer has not been made whether it is preferable to stock the tires until the radioactivity will permit the retreader or aircraft mechanic to handle the tire, or if it is preferable to "wash" the tire by venting inspiration to dilute the radioactivity. Maybe some will prefer washing, and some will prefer to store the tire a few days. The point that is important is that if you wish to stock the tire, there is nearly no diffusion of the tracer outside.
Q: Was there any degradation of the tire as a result of the test? *RQ:* By injection of gas or by radioactivity? *A:* By injection of gas.
A: No. Some tire and retreading companies require the air needle test at very high pressures – I believe eleven or twelve atmospheres. It seems to me that this is very severe – a destructive test, not a nondestructive test. Our aim is to reduce this pressure and we feel that three atmospheres is ample. Additionally the quantity of gas injected is much lower than is normal for an air needle test.
Q: You said that you hoped to see the machine developed to be able to test 100 tires per day. Have you also thought of what the cost per tire might get down to?
A: It is difficult to respond because we are now making a semi-final automatic prototype. I think that in maybe six months we will have your answer, but first we can consider the cost of the consumable Xenon, which I guess to cost

maybe 40¢ to 50¢ per tire. As for the machine itself, it is difficult to answer because of many variables in use. I think the highest cost on limited use would be $3 or $4 but don't hold me to this as a concrete figure.

Q: Assuming you have a large and a small tire with defects of the same magnitude. How will the trace curves indicate that you may have a greater concentration of gas in the smaller tire?

A: In the example I showed you, the probe is a scintillation detector probe, having a crystal that is 1/3 in. thick and 1-1/4 in. in diameter and we have made no examinations smaller than that – so the diameter of expiration is about 2 in. But if you want to make faster examinations you can use a bigger probe. If you want a more sophisticated examination in a longer time, you can make more precise collimation. What we have is a compromise, – maybe not the best – and after more experimentation we may select a different size.

STATUS REPORT OF NONDESTRUCTIVE TIRE TESTING IN DEPARTMENT OF TRANSPORTATION

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One basic problem for retreaders is that they have very little control over the condition of half of their raw material, the carcass. Work at DOT in finding flaws in tire carcasses has established that an experienced inspector can find most of the flaws in a carcass which will cause that carcass to fail. However there are not enough experienced inspectors to go around and they are costly to train and maintain. As part of its work for NHTSA in seeking means for finding flaws in tires and relating these flaws to failure, TSC is developing two pieces of equipment which may be useful to retreaders:

(a) An ultrasonic tire inspector

(b) A tire carcass proof test system

The paper describes these systems and the work in conjunction with the Tire Retreaders Institute which we propose to do to evaluate their effectiveness.

Special emphasis during the development of these systems has been given to keeping them practical and economical so that if the retreading community wishes to reproduce them for their own use they will be able to do so quickly and economically. Other work in nondestructive tire inspection will be described in terms of its context in the overall DOT effort.

The work described was done under auspices of the National Highway Traffic Safety Agency, M.J. Lourenco Coordinator. The purpose of the project is to develop cost effective nondestructive inspection equipment for application in three areas: New Tires, Retreads, and Drive on Inspection of Tires in Service.

The paper here is devoted to a description of the work going on in development of test equipment which could be of utility to retreaders. TSC has two projects in this area, the first is development of an air coupled ultrasonic test set. The second is development of a tire casing proof test.

The problem of development of a nondestructive ultrasonic test system as has been said previously is to make it both efficient and cost effective. At the beginning of the project our idea of the size of this task was shown in slide 1. You can see that we thought the system would be good if we could get the price in production down to $10,000. After talking with tire people like Al Janarelli, Phil Taft, and Ed Wagner we modified our thinking about the ultimate system cost and production rate. We now think that a system costing around $3000 can be built to process a tire at a rate of one a minute or a minute and

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TSC

TRANSMISSION ULTRASOUND

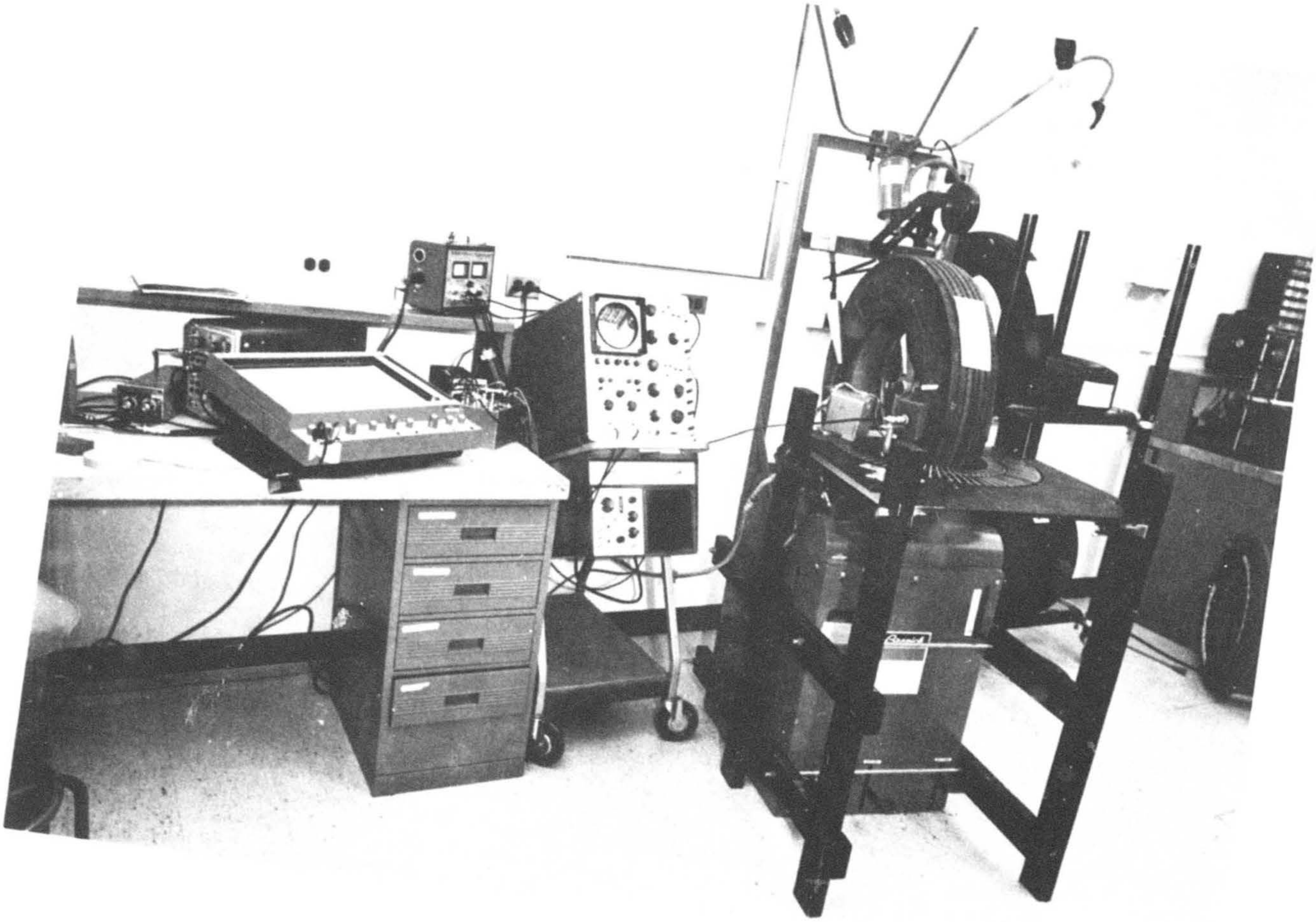
DESCRIPTION:	BASED ON THE ATTENUATION OF SOUND (25KHZ) THROUGH THE TIRE CARCASS
DEFECTS MEASURED:	CUTS, CRACKS, BROKEN CORDS, VOIDS, SEPARATIONS, THICKNESS
DISCRIMINATION ABILITY:	LIMITED TO GROSS DETERMINATION OF SURFACE OR INTERNAL DEFECT TYPE
DISADVANTAGES:	LIMITED DEFECT DISCRIMINATION - REQUIRES ACCESS TO INSIDE OF TIRE
ADVANTAGES:	MODERATE COST, SIMPLE, CAN BE AUTOMATED
BEST APPLICATION:	POST-COMPLIANCE TEST INSPECTION - RETREAD CARCASS INSPECTION
STATUS:	SINGLE CHANNEL BREADBOARD IN OPERATION SINCE OCTOBER '71 18 CHANNEL UNIT MARKETED BY AIR TREADS INC. FOR AIRCRAFT TIRES
POTENTIAL:	INSPECTION TIME - 30 SECONDS DEVELOPMENT COST - $ 250K UNIT COST - $ 10 TO 30K

HS-03 11/10/72

SLIDE 1

a half. The first system we built is shown in Slide 2. This suffered from two massive problems. The first was that when it inspects old tires they are so floppy that a uniform reading can't be obtained. The second problem from a production standpoint is shown in Slide 3. The transducer on the inside of the tire had to be up close to the surface of the liner in order to get enough signal for the system.

At this point, it was decided to let a contract to have these two problems solved in addition to a few associated with improving the electronics. Essentially the problems with the electronics were minimal, the thrust being to develop a workable simple display. The resulting equipment is shown in Slide 4. It can clearly be seen that you could talk a pot into boiling before you could talk anyone into building that unit in production for less than three thousand dollars. When received at DOT the unit was not operating. A decision was therefore made to redesign the unit to simplify it. In principal the machine shown had a gear box and servo drive outside of the tire which would permit three receivers to be scanned around the tire. One would scan the tread. One would scan each sidewall. Through linkages another set of transducers would scan the inside of the tire using another servold gearbox and hopefully the transmitters and receivers would remain opposite one another. Aside from the complexity of the system the major drawback was that there was no way a tire could be mounted on the machine without knocking one of the inside transducers out of kilter.



SLIDE 2

Slide 5 is a block diagram of the new system modified. It was experimentally determined that one transducer would ensonify almost the complete inside of the tire. Moreover the transmitter itself is located inside of the bead rim so that it is relatively out of the way while the tire is being mounted and dismounted.

Slide 6 is a picture of the new transmitter mount. The only place where this arrangement is not highly efficient is in the upper sidewall near the bead, and other arrangements could be made for these. It will probably be necessary to move the transducer to accommodate changes in inspected tire rim diameter although this is not entirely certain at this reading.

Slide 7 is a picture of the new machine as modified in the new configuration. We have gotten rid of most of the knobs and wheels which were mostly for orienting the inside transducers to the outside.

In practice the way this machine now operates is as follows: The left hand rim is moved aside to permit mounting a tire.

A tire is then placed with its bead on the right hand rim and the left hand rim is moved into place and locked there. A valve is opened inflating the tire to 5 PSI and a switch is turned on. The tire is then rotated a total of five times and all transducers have by this time scanned the tire.

The system is set up for two display methods, a video presentation on a storage scope or an audio signal. Since the video display costs $3000 as it comes from Tektronix it is pretty much precluded from being a candidate for a display on a $3000 tire inspection machine. The other display mode is a meter and a bell. The meter will be red banded at a point that represents a flaw in the tire and the bell is adjusted to ring if that threshold is exceeded. All twelve channels will be individually capable either of displaying their signals on the storage scope or actuating the bell.

At this point in time, the unit is awaiting receipt of the display electronics and a complete set of transducers. Each transducer sells for five dollars so that if it is damaged it can be cheaply replaced.

Data from the memory scope can best be described by looking at some typical recorder traces from the system as originally conceived and as it now operates:

Slide 8 is a typical trace of a tire showing tread runout as a result of a floppy casing. The lines wander all over the place and this means nothing.

Slide 9 is scan of the same tire with the geometry stabilized by new holding equipment. With the tire inflated and its geometry in better array several important things come out of the hash.

Slide 10 is an example. The tread center shows belt breakage all the way around the tire. A similar situation will show up in the belt edges.

In order to confirm that we truly see flaws in casings we plan a rather ambitious testing program.

The program for verification of the machine performance has been designed to provide a data base for NHTSA in its rules-making function.

A cooperative program has been instituted with TRI and ARA. Essentially it consists of the following:

1. TRI and ARA will each provide DOT with 120 tires representing the spectrum of cherry picked casings available to the industry. These casings will be from all common sizes and constructions of 15" rim diameter. They will where possible represent a complete Geographic distribution. At least 20% of the tires are radials.

2. The tires are presently being logged in at DOT and are starting to undergo nondestructive inspection. First they will be inspected by Holography since this is as sure a way as is known today for finding separations. Next they will all be run through the modified air coupled ultrasound system. The data from the two techniques will be entered into a computer and stored.

3. The tires will then come under the direction of Al Janarelli and Ed Wagner and be returned to their respective facilities and inspected, retreaded, and returned to DOT. DOT plans to run these tires on appropriate test cars for some mileage to be determined later but probably 5 to 10,000 miles and then reinspected using holography and ultrasound.

4. At this point test data will be given to both TRI and ARA (for their interpretation) and a decision will be made as to the effectiveness of the new inspection system for identifying flawed casings. The tires being shipped here are coming from where they will be retreaded. While we will get some general data on the effectiveness of the nondestructive testing techniques it represents a major opportunity for those participating to correlate the performance of their tires with building techniques and casing types.

Another idea we had was the development of a casing proof test. Actually this was an outgrowth of some discussions

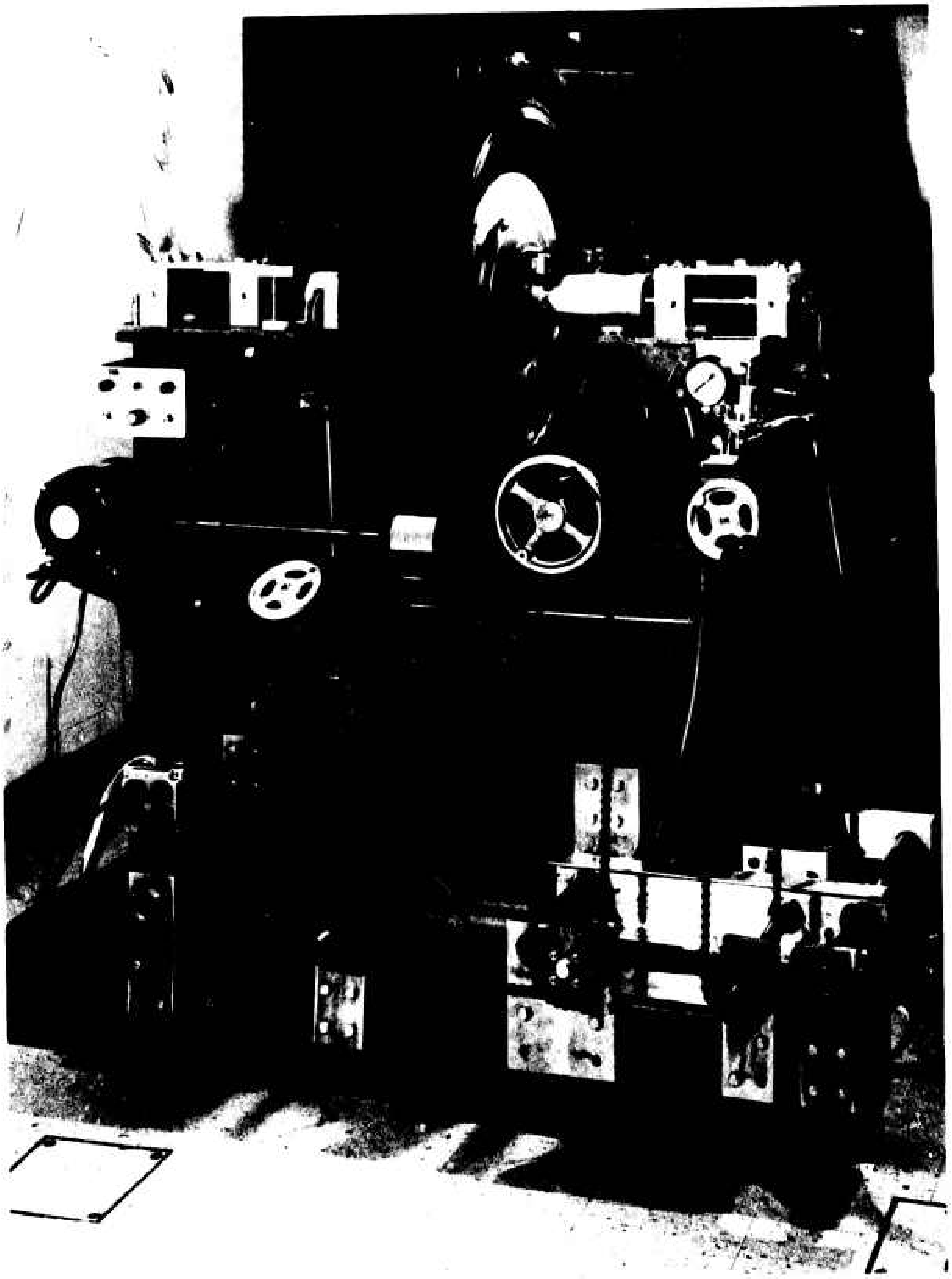
with Professor S.K. Clark at the University of Michigan. Professor Clark had been working for some time on individual tire components like plycord and he found that stressing these components sometimes tended to improve their fatigue life. He then made the corrolary assumption that stressing tires wouldn't hurt them, moreover there might be a lot of information to be gained by such an exercise. So as a part of the work on tire cord composites, the University of Michigan performed pressure tests on a number of old tire casings.

Slide 11 shows a schematic of the apparatus. There are no good pictures of the device for reasons that will become apparent later.

Figure 8

Figure 9

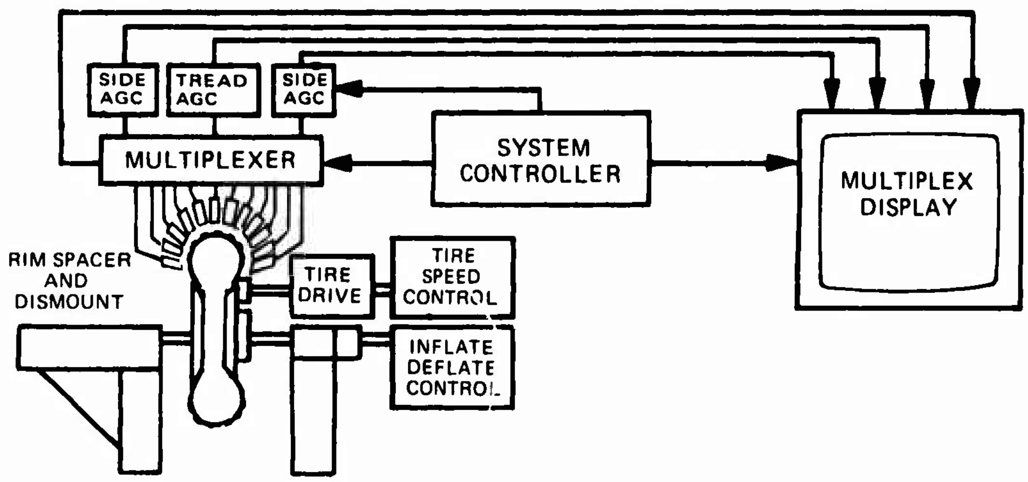
SLIDE 3



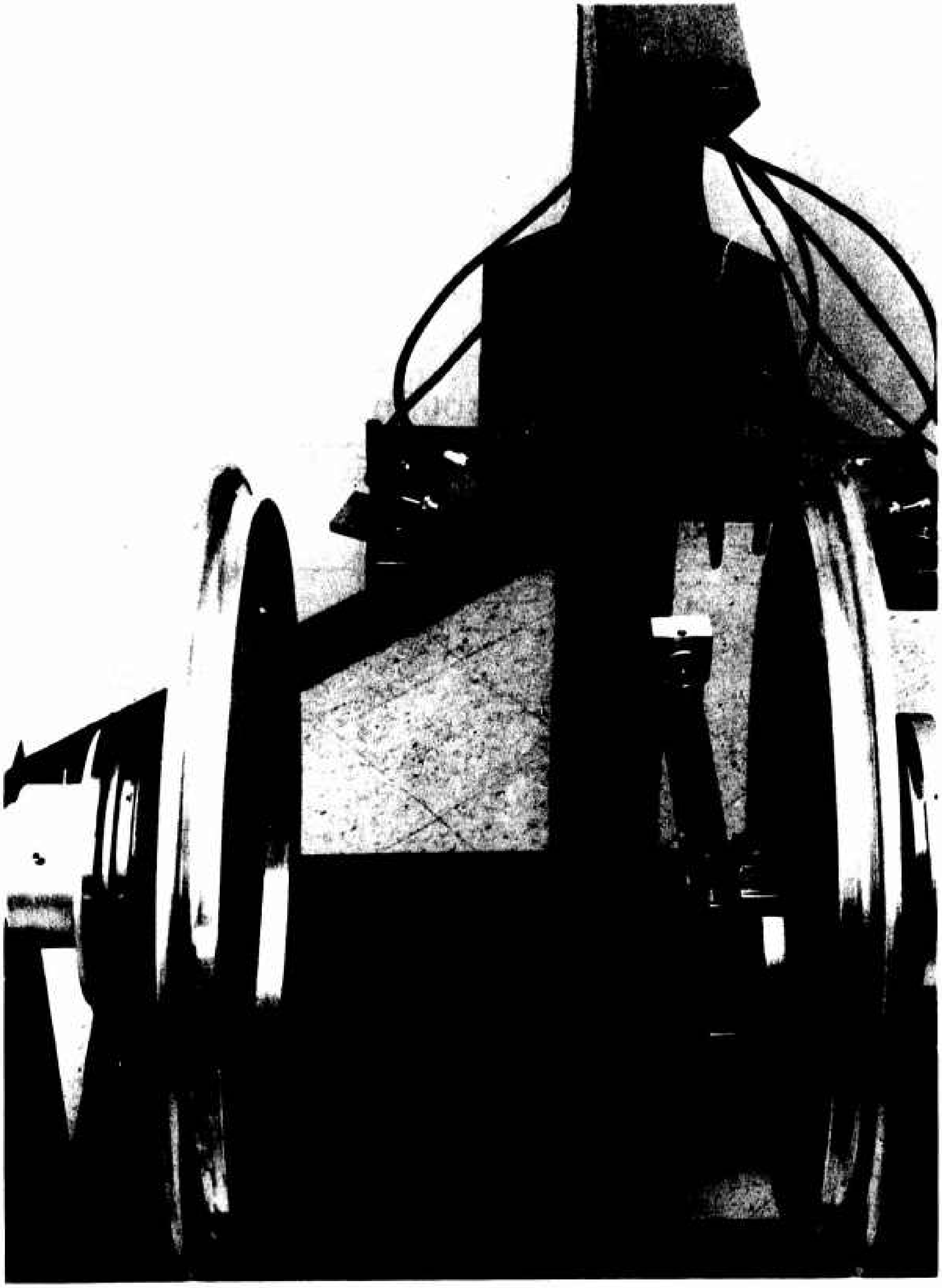
SLIDE 4

METHOD:

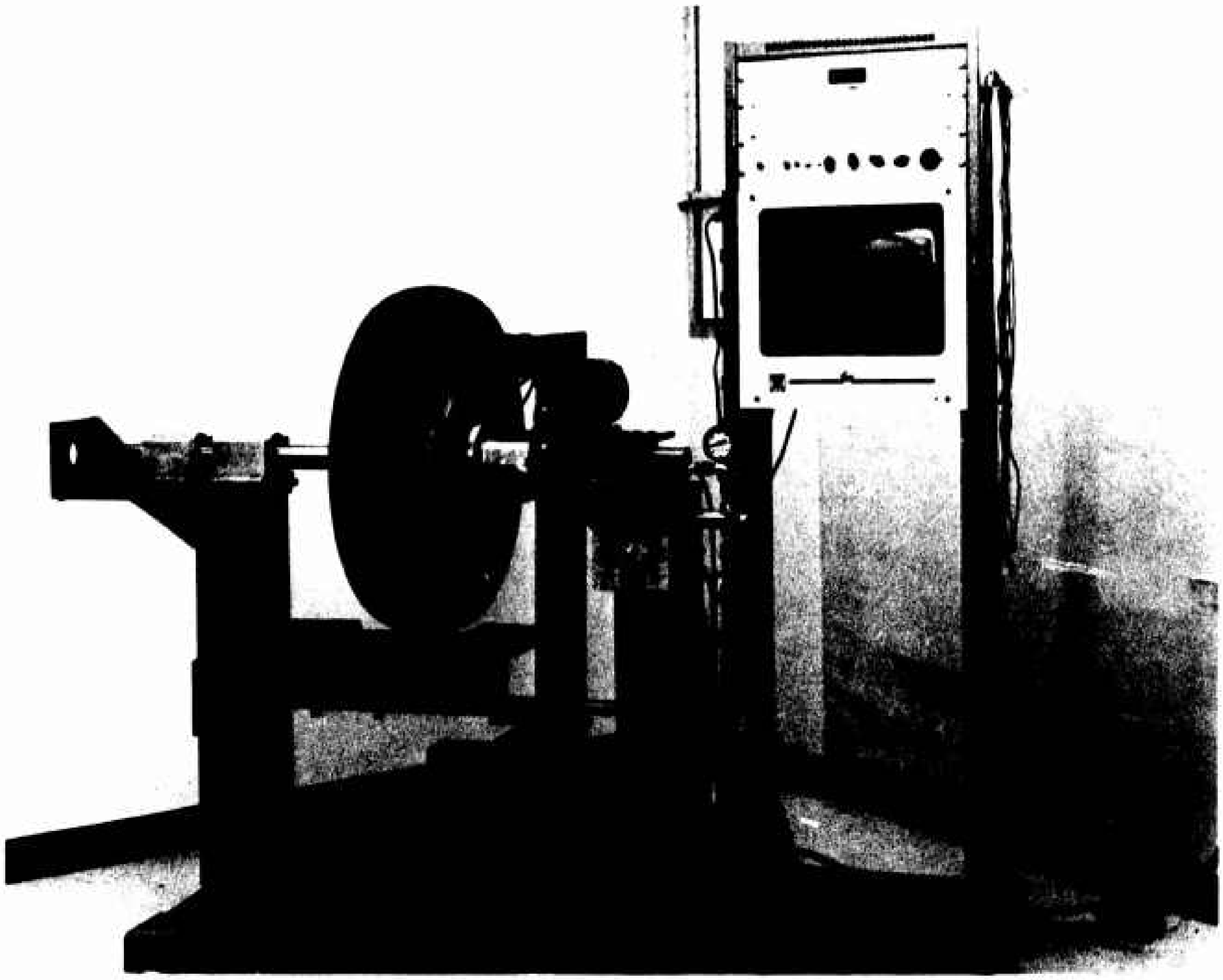
TRANSMISSION ULTRASOUND BLOCK DIAGRAM



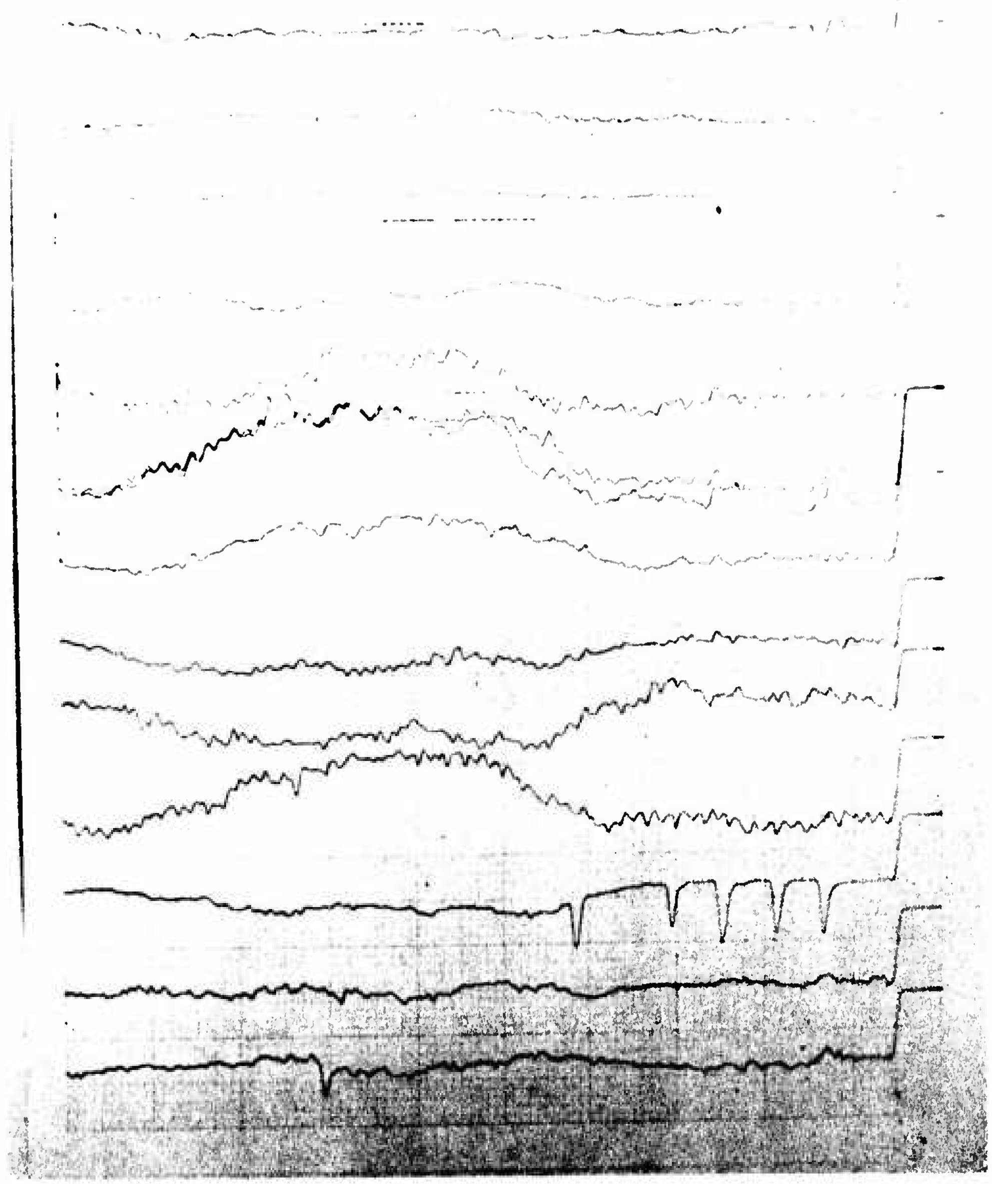
SLIDE 5
CASING FLAW INSPECTION



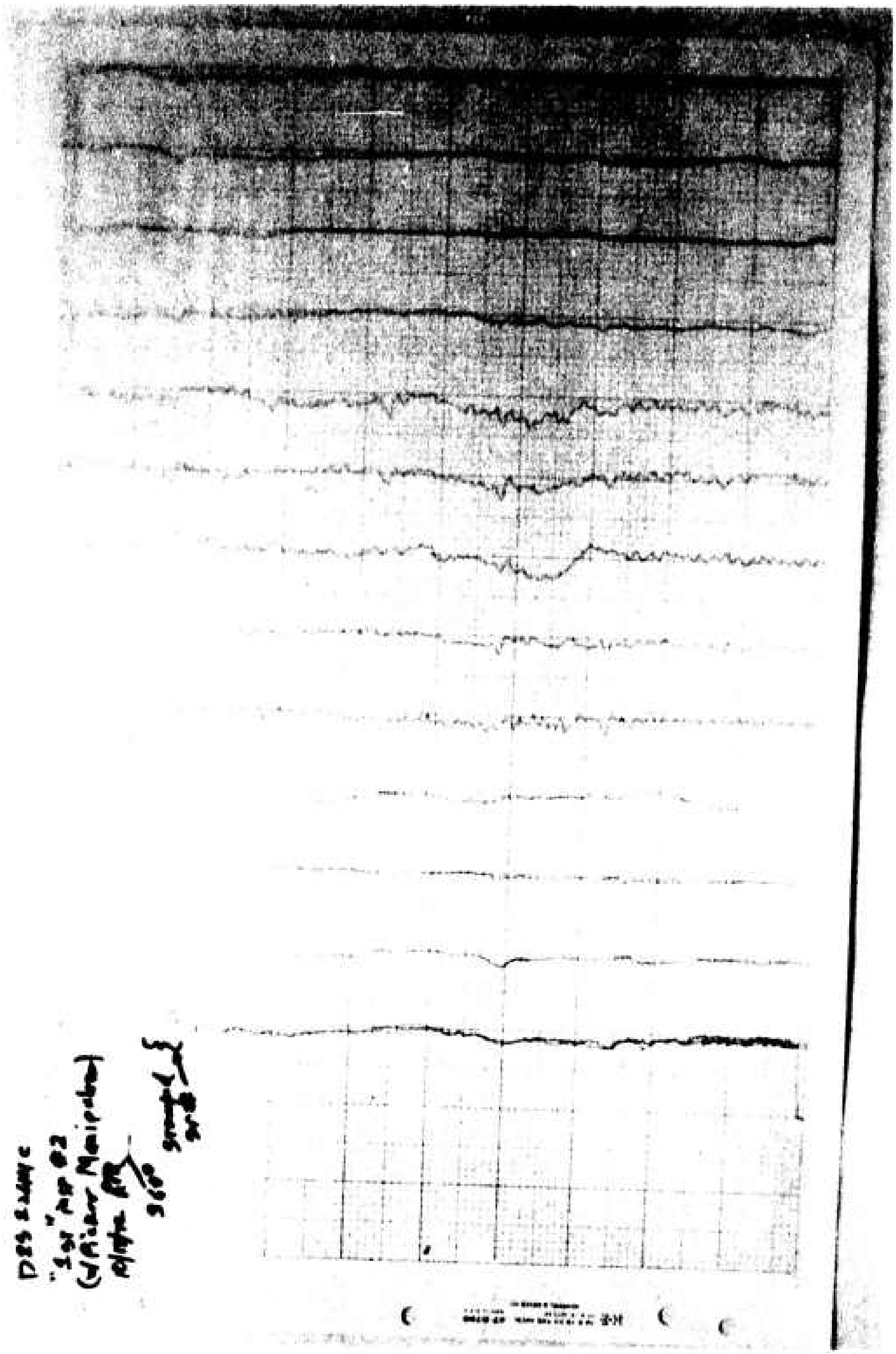
SLIDE 6



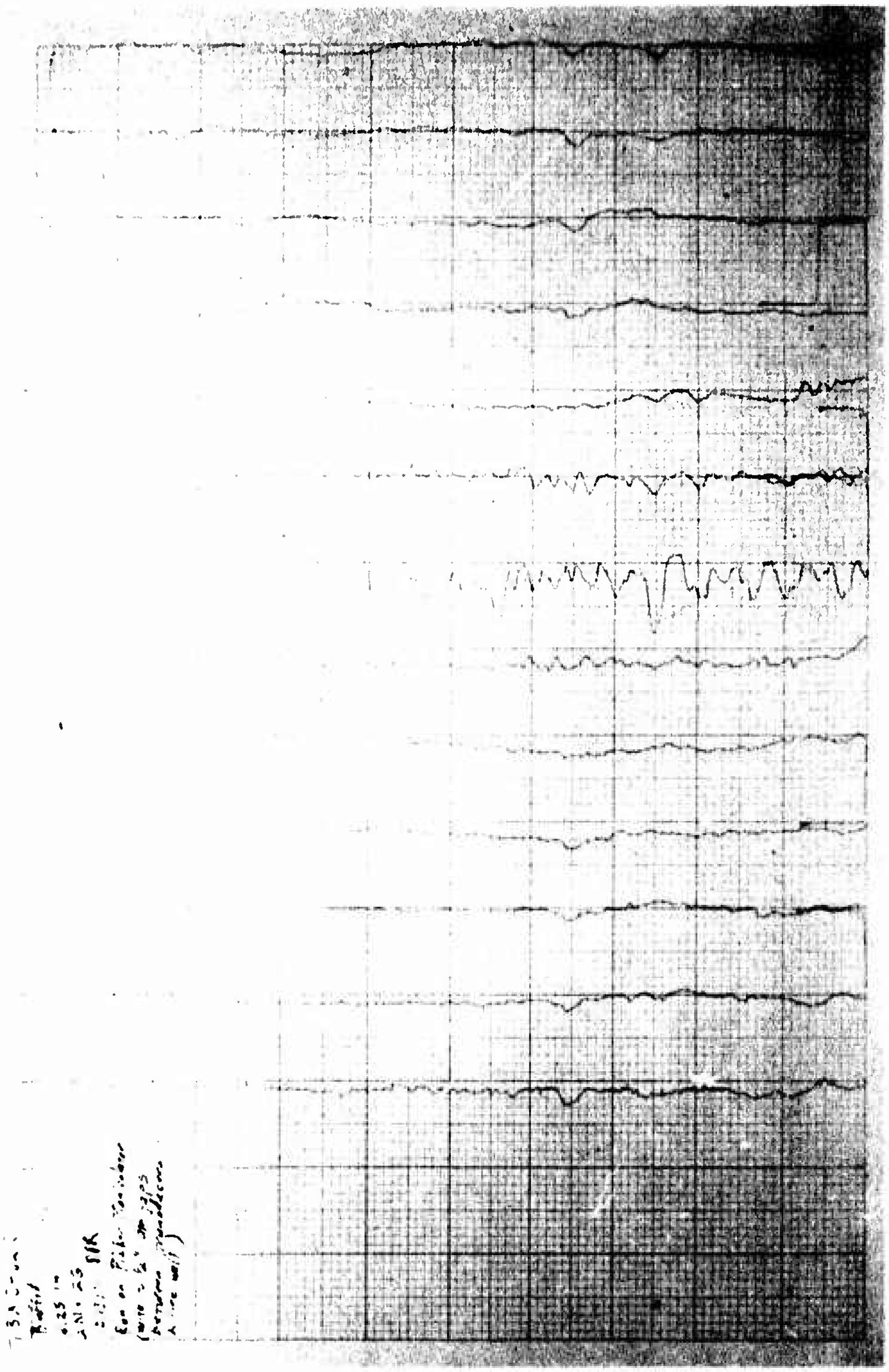
SLIDE 7



SLIDE 8



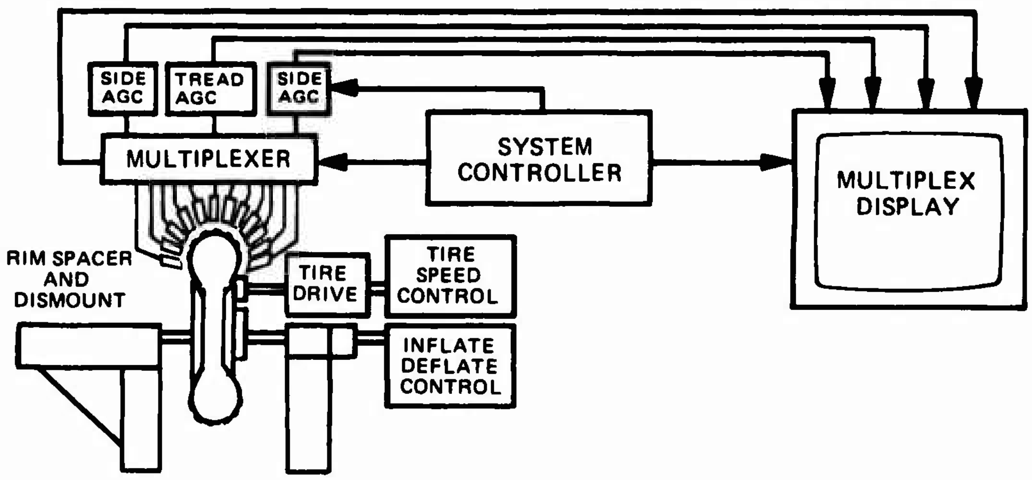
SLIDE 9



SLIDE 10

METHOD:

TRANSMISSION ULTRASOUND BLOCK DIAGRAM



SLIDE 11
CASING FLAW INSPECTION

There is old precedence for bursting of tires to measure their strength. Every tire company has a hydrostatic burst room and in one of his books Andy White describes burst tests on tires before 1965. We are all aware of the danger associated with bursting tires using air as an inflation medium but it is such an easy thing to do we will continue to emphasize its danger. Slides 12, 13 and 14 accompanied the following letter from Professor Clark.

Dear Steve:

On Saturday morning last we burst a tire using nitrogen from a tank instead of water in order to get some idea of the explosive forces which would have to be contained by any kind of a gaseous pressurization system. The tire was contained in a steel armored wooden box which we had used for all our water pressurization experiments quite successfully, without having any structural problems with it. The tire broke at 215 psi and took two sides and the top off the box. We were out in the hall, having wisely vacated the room, but pictures 1 and 2 will show you what remained of our protective box. Del Lavery has seen this box and may also appreciate looking at the pictures. The tire is also shown in these photos. We now conclude that in future designs the use of a water filled bladder is probably the best way to go. The noise was deafening. I thought you might be interested in this.

Sincerely yours,

(Signed, S.K. Clark)

SKC/bp

P.S. The small tires shown in the photographs are only incidental. They were used as shock absorbers between the large tire and the ground.

SLIDE 12

SLIDE 13

SLIDE 14

Any method using a liquid for reducing stored energy is preferable to use of air or other gas.

The first experiment carried out covered 100 tires of differing construction and type. Construction was inferred to affect the most probable location of failure under pressure. Two ply polyester tires failed most often in the crown. Rayon bias belted tires failed in the sidewall and radials failed most often in the bead. Slide 15 shows a burst of a two ply polyester at tread center at 235 PSI. The casing shows even wear and almost no remaining tread. Slide 16 shows a sidewall burst. These generally tend to be closer to the shoulder at the hinge point. Slide 17 shows a bead break at 240 PSI.

Slide 18 shows the difference of the burst distribution with construction. Y is percentage of median burst pressure and x is percent of tires failed. Thus 90 percent of the 2 ply polyester tires had failed at the median burst pressure of 212 PSI for all tires where only 35% of the rayon and 4 ply bias tires had failed.

In addition to monitoring median burst pressure on acoustic emission sensing system was used to monitor the breaking sounds within the tire to determine whether there was any relationship between the sounds given off by the tire and its ultimate burst strength.

Slide 19 shows what we really wanted to see; two identical tires, one with a cut belt and the other with no damage. The number of pops and crackles is monitored, accurately counted electronically and plotted against pressure until failure of both tires.

Slide 20 shows the level of two acoustic emission signals from two other identical tires. Both tires failed at about 215 PSI but one had 40,000 counts at failure and the other had over a million.

It was therefore obvious that we still have a lot to learn about accoustic emission properties of tires.

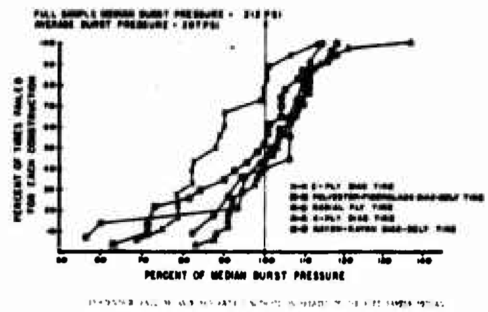
The steps or bursts of energy are generally significant in acoustic emission studies and these will be monitored closely. Also the rate of fill of the tire versus pressure seems to be important and we will determine whether this is related to residual casing service life.

In conclusion, reports concerning the things done at DOT in Cambridge are being generated and I would be pleased to send them on when they become available.

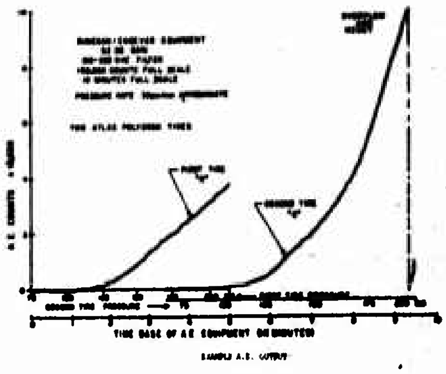
SLIDE 15

SLIDE 16

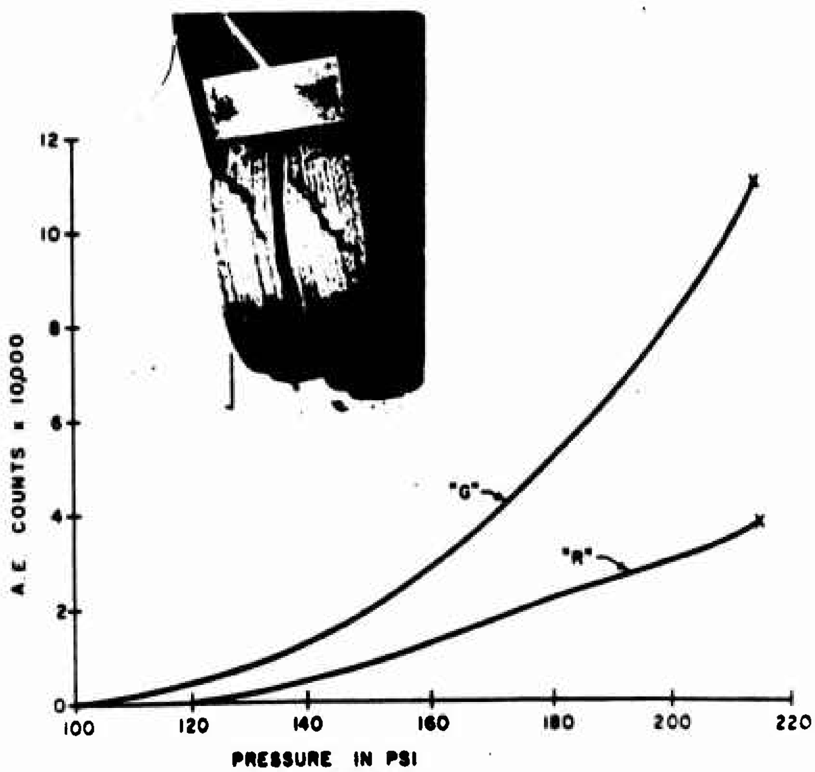
SLIDE 17



SLIDE 18



SLIDE 20



ACOUSTIC EMISSION OUTPUT FOR TWO IDENTICAL TIRES:
TIRE "R" UNDAMAGED; TIRE "G" WITHOUT BELT

SLIDE 19

QUESTIONS AND ANSWERS

Q: Could you tell me in your application of acoustic emission you have a plot there of two tires, one showing higher counts but both bursting at the same compression?
A: That's right.
Q: How does that indicate applicability of acoustic emission?
A: Well we think in terms of the tires not being, it represents one of the enigmas we have to deal with. A tire with a broken belt can be driven providing it is not over stressed until its tread wears out, and somebody will say that tire is completely serviceable. On the other hand, if that tire is stressed on some level well above normal it would probably fail in service, so we see two conditions, we see an intrinsic service life of a tire under most stress conditions, and we see a tire under its maximum stress conditions. We think it is not good to have a damaged tire out in a life which is risking being stressed to its maximum service condition. So we would therefore say that we would like to see some tires, we would like to call out those tires that had any obvious damage that will cause problems in most of their use. Does that answer it?
A: No.
Q: The point is, I believe, that there is probably some correlation between acoustic emission and degradation process. My question is that if we show two curves there, with different slopes, more emissions from one than the other and they both burst at the same pressure, then what does that show?
A: Well it shows the first test isn't the complete answer to the integrity of the tire and I guess that nobody would say that it was but it may be one of the answers of tire integrity can also be the integrity of each of its components. So we have two tests which we are showing up here. One, you can listen to a tire, if you have ever inflated a new tire, it will whistle and sing when you first blow it up, it will have a lot of acoustic emission. But if the characteristic of that emission increases, you may have a condition in where there is some damage with a new tire, which you would like to call out. Neither acoustic emission nor bursting pressure is a valid criterian alone for this kind of tire or accepting but the two may give you some information as to what's going on within the tire which you might be able to use.
Q: Once you have finished your development and you can have this $100,000 equipment that does this job as you describe, what does DOT see as the position of that, are you involved in just the technology which is then available or do you plan to go further with that?
A: We attempt to develop the technology because we think in that particular application, in that instance, the technology looks like the only physical principle, the reflection of ultrasound looks as if its the only physical principle which will be capable of inspecting a tire. Our purpose in developing it, is to find a screening device for compliance testing of tires. In other words, we now test 4,000 tires, it would be nice if we could test 40,000 tires and get a much clearer representation of the national usage of tires. So that's the purpose of the development of our equipment. A concomitant purpose is to demonstrate to industry that there is a technique which perhaps industry couldn't have afforded to bring this far on a high risk basis. To demonstrate to industry that there is a piece of equipment that could be bought relatively cheaply because x-rays cost of this order and which can do more than an x-ray and which can be used at the rate of one every 10 seconds for a higher percentage of inspection of their tires and it therefore may be useful to industry. We intend to check out tires. If it works in our compliance applications, we'll leave it until the people in another division of DOT picks it up as a rules making device. Transportation Systems Center has no authority, we are not rules making people. We're technology, we provide information to people who legislate, or make the rules, we have none of that authority and don't want to get involved in the politics of rules making. However, we were asked to do this by the National Highway Traffic Safety Agency with a view to perhaps reducing the cost of the compliance tests which we are now using.
Q: In the reflective ultrasound method, have you evaluated 6 – 8 – 10 ply tires?
A: We have looked at 6, 8 and 10 ply tires and its possible to see through them. I think you will probably get better information about that from Gwynn McConnell and others who are more heavily involved in that. I think the thing we are trying to do here is to work out a technique for getting all the information we can from reflection ultrasound. That may or may not be necessary in more direct applications such as looking at aircraft tires. I suspect that separations are far more important to aircraft and truck tires than they are to passenger tires.

U.S. AIR FORCE TIRE USAGE EXPERIENCE

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To determine if anomalies detectable by nondestructive testing of aircraft tires would provide more reliable performance and pay for the cost of NDI, the Air Force analyzed tire usage and failures. The study covered more than two million new tires and about 400,000 rebuilt tires used over the past several years. Of the 2.5 million tires used, only ten failures could be identified to ply separation. Based on the number of failures which may have been prevented by nondestructive testing, the number of tires which would have been disposed of because of ply separation anomalies identified by nondestructive testing but which did not fail in operation, and the cost of nondestructive testing, it does not appear that 100 percent nondestructive testing would provide more reliable service and would not be cost effective for the U.S. Air Force. However, NDI studies should be continued to establish its optimum use. (Paper not presented.)

CHAPTER IV – HOLOGRAPHIC TIRE TESTING

COMMENTS UPON THE STRUCTURAL INTEGRITY OF TRUCK TIRES AS OBSERVED BY HOLOGRAPHY

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ABSTRACT

A brief review will be given of recent methods employed in the holographic nondestructive testing of radial truck tires. Comments will be made on both equipment and procedures. The prime purpose of this paper will be to answer the basic question: Do separations propagate? Twelve specific examples of the propagation of separations in steel wire radial truck tires are presented. Based on our observations, separations always propagate. However the more important question is: At what rate? Comments are included in answer to this question of rates of propagation.

INTRODUCTION

Holographic nondestructive testing [1,2] is uniquely suited to the evaluation of pnuematic tires. This uniqueness is best explained by briefly describing the process by which the tire is tested. An explanation of the test method is, however, not the purpose of this paper. Our basic objective is to answer, via the holographic method, the basic questions: Can one observe the absence or presence of structural integrity in truck tires and what influence does that structural integrity have on the performance of the tire? Is it possible to observe the propagation of inner ply separations as a function of mileage and most importantly do these separations bring about premature failure of the tire?

Previous observations [1] have clearly shown that truck tires containing inner ply separations of a given size and geometrical location in the tire carcass, as observed by HNDT, do fail prematurely. Of paramount importance is a detailed understanding of the answer to the question, do inner ply separations propagate; at what rate and under what conditions? Conversely, do tires containing a high degree of structural integrity have a marked increase in mileage without failure.

BRIEF GENERAL DESCRIPTION OF HOLOGRAPHIC NONDESTRUCTIVE TESTING

Very briefly, holography is a two beam photographic process [2], that stores complete visual data about an object and reconstructs a three dimensional image that is visually identical to the original object. An object, in this case a tire, is placed as shown in Figure 1. The tire is illuminated by two beams taken from the same primary laser beam, one the object or tire illumination beam and the other a reference illumination beam. A portion of the light reflected by the tire, along with the reference light is recorded on a photographic emulsion. The process is similar to ordinary photography, except for the presence of the reference light and the fact that a laser is used. The high resolution, photographic film is then developed and dried. The three dimensional image is then viewed as depicted in Figure 2.

We use the more complex process of 3D laser photography to enable us to set up a 3D interferometer. By doing this, one can observe minute displacement changes in the tire as a function of an applied stress.

Holographic interferometry is merely a method for measuring differences in surface displacement of an object in millionths of an inch. In actuality we want to observe a bulge in a tire as a result of a ply or tread to carcass separation. Interferometry allows us to measure that bulge, even when it is extremely small. Furthermore it provides a means of quantitatively determining the exact amount of surface displacement (bulge or stretch) as a result of an applied stress. The stress is purposely applied to observe the bulge or induced stretch of the tire. In conclusion, HNDT (Holographic Nondestructive Testing) is the purposeful application of a stress to a body such that the amount of stretch can be quantitatively observed. By quantitative stretch we mean the topological change in shape, between the original shape and the final shape after stressing.

RECORDING OF A HOLOGRAM

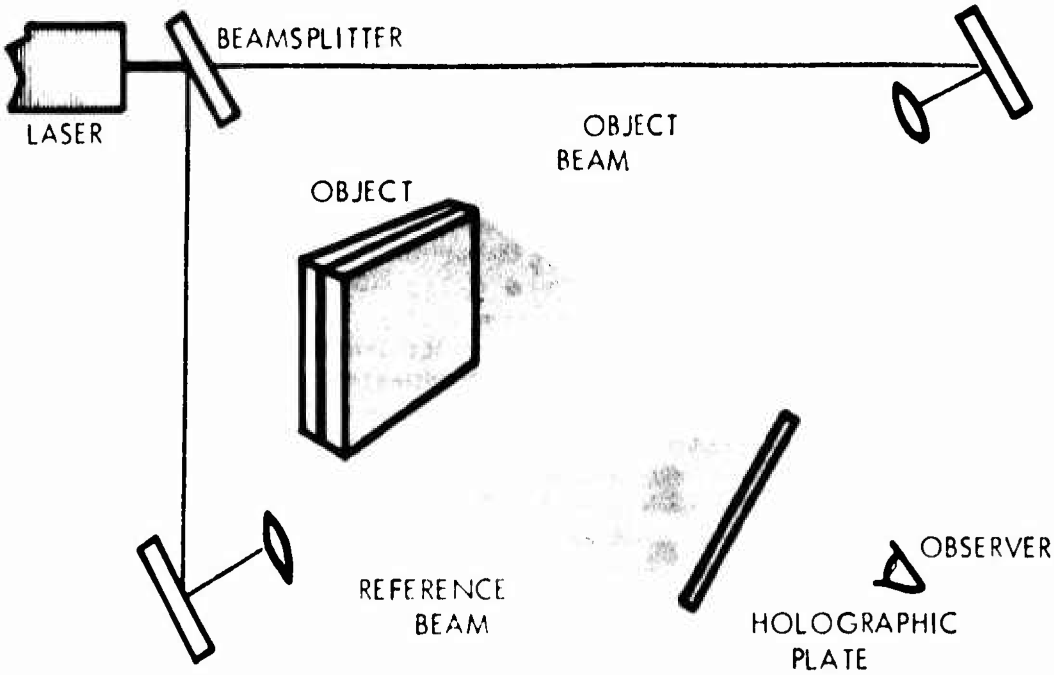


FIGURE 1
RECORDING OF A HOLOGRAM

VIEWING OF THE 3-D IMAGE

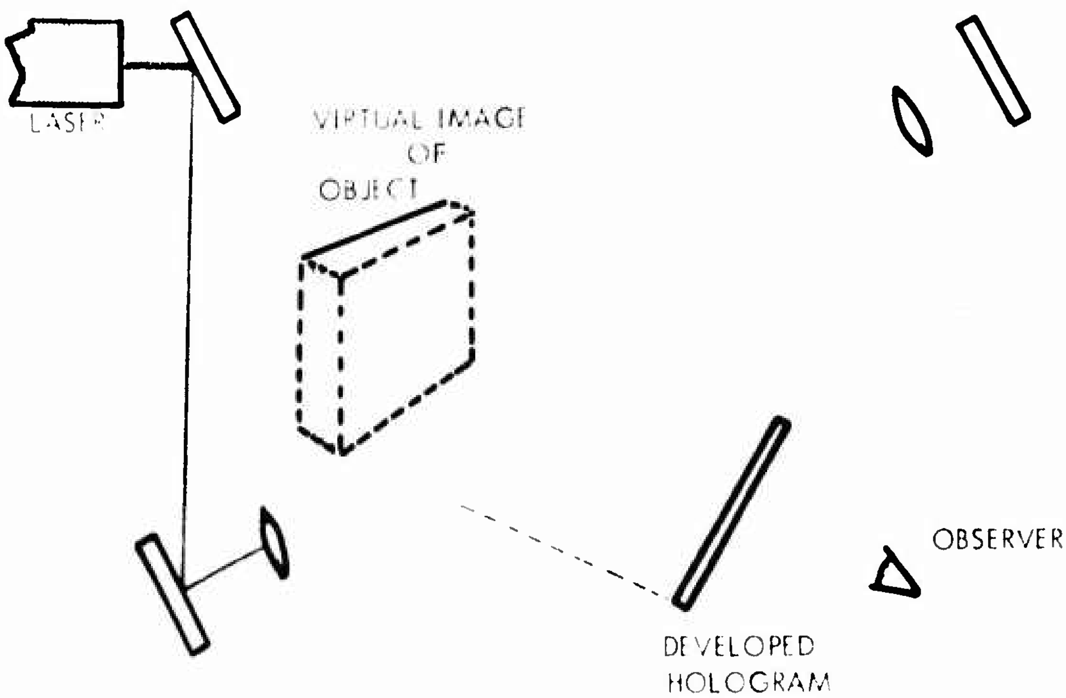


FIGURE 2
VIEWING OF THE 3-D IMAGE

An object can be stressed in a variety of ways; by mechanical loading, heating, changing air pressure, etc. In the case of a tire, the application of a vacuum has been found to be the best loading procedure, because the stress is uniform and the tire dilates with applied vacuum due to both the entrapped air in the carcass and the natural outward creep of the rubber due to the reduction in atmospheric pressure. An interferometric camera is placed between the beads of the tire as shown in Figures 3A and 3B.

A hologram is made (90° view at a time) of the interior of the tire without a vacuum (note A, Figure 4) applied. Without moving the film a vacuum is then applied and a second exposure is made. As a result of the vacuum, air inside the carcass and air inside existing separations cause the tire to stretch, resulting in an interferometric pattern (topological surface map – which is a record of the amount of stretch between the before and after condition) as shown in part B of Figure 4.

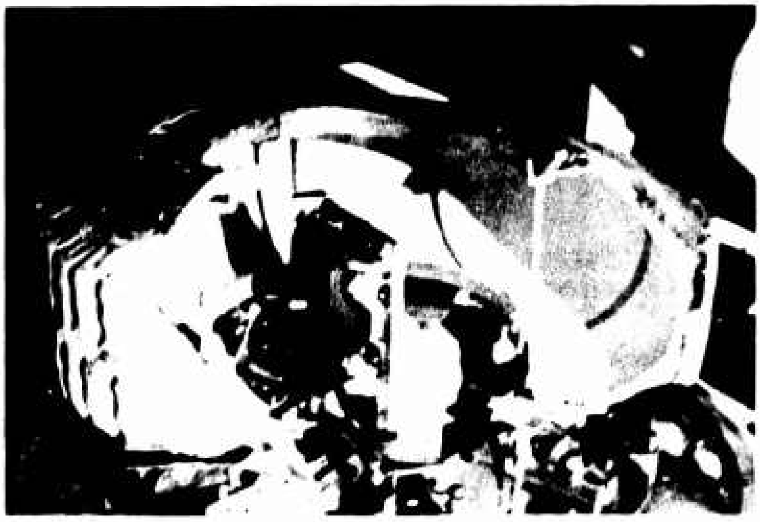


FIGURE 3A
TIRE TEST CONFIGURATION

FIGURE 3B
TIRE POSITION IN MACHINE SHOWING
SPREADER POSTS

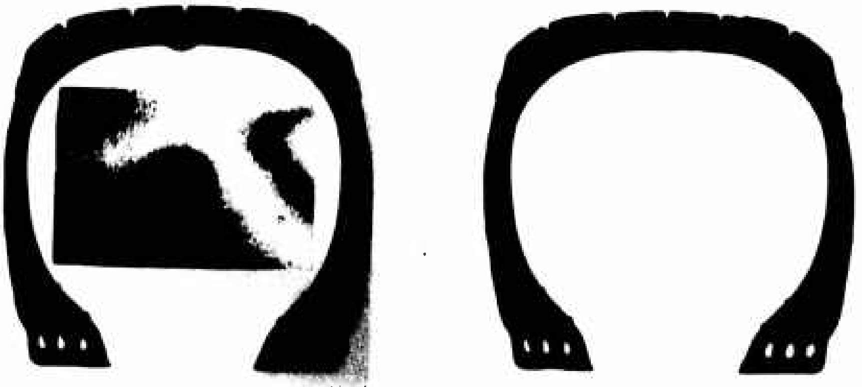


FIGURE 4
BEFORE AND AFTER VACUUM – WITH HOLOGRAPHIC PATTERN OF SEPARATION – AFTER VACUUM

It is important to note for the purpose of future discussion that overall dilation or stretch of the tire takes place in addition to the more dramatic stretch caused by the presence of a large separation. Before proceeding, the above comments can be summarized by noting Figures 5 and 6.

In Figure 5 two plies P_A and P_B are shown. No inner ply separations are present between P_A and P_B. Now note that when the observer views the developed hologram, he sees the background fringe pattern depicted in the figure. This background pattern is a result of the forward motion of the surface SS, caused by the reduction in air pressure (vacuum applied) over the outer surface of the tire. The number of fringes per unit area, as in conventional interferometry, tells us exactly how far forward surface SS has moved.

Next, observe in Figure 6 that an inner ply separation is present at D between plies P_A and P_B. Now in addition to the background fringe pattern, there also exists a unique bulls eye fringe pattern associated with the added forward motion of the separated region. This total forward motion of the surface S^1S^1 is consequently recorded quantitatively by the fringe pattern shown in Figure 6. Hence a defect (separation) is readily observable over and above the background pattern.

This background fringe pattern is of just as great a value as the bulls eye pattern brought about by the separation, since it reveals the overall strength of the tire system. Some very interesting fatigue information can be obtained by observing this background pattern.

The bulge or stretch of the inner ply separation is significantly enchanced by the fact that surprisingly large quantities, relatively speaking, of air are trapped in the separated region. This air is at atmospheric pressure. When a reduction in air pressure outside the tire carcass is brought about, the atmospheric pressure inside the carcass exerts a significant outward stress in the direct vicinity of the separation bringing about a pronounced displacement due to the separation as noted at D on surface S^1S^1 in Figure 6*.

Each fringe is a contour of equal displacement or stretch. The reader might compare this to a geographical elevation map where each contour line on the map corresponds to a set increase in elevation.

*Instead of speaking about stress-strain relationships, one considers stress-displacement relationships. The pattern reveals the displacement $\Delta \ell$ brought about by a given stress, α. Note that strain in its simplest form can be represented by $\Delta \ell / \ell$ where ℓ is a unit length in the direction of the applied stress. Therefore, we do not observe strain directly, but rather displacement $\Delta \ell$.

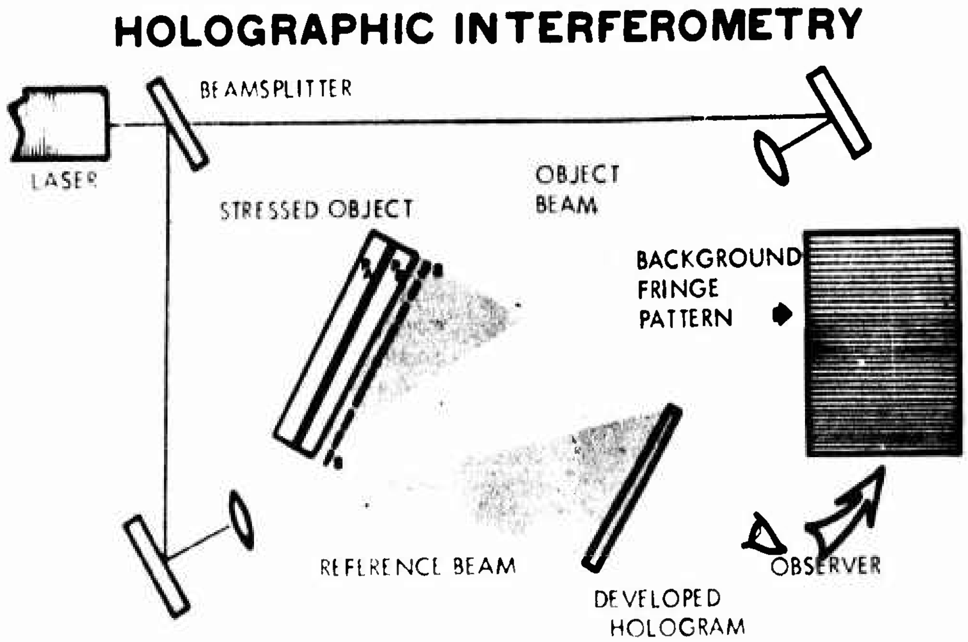


FIGURE 5
HOLOGRAPHIC INTERFEROMETRY WITH BACKGROUND FRINGE PATTERN ONLY

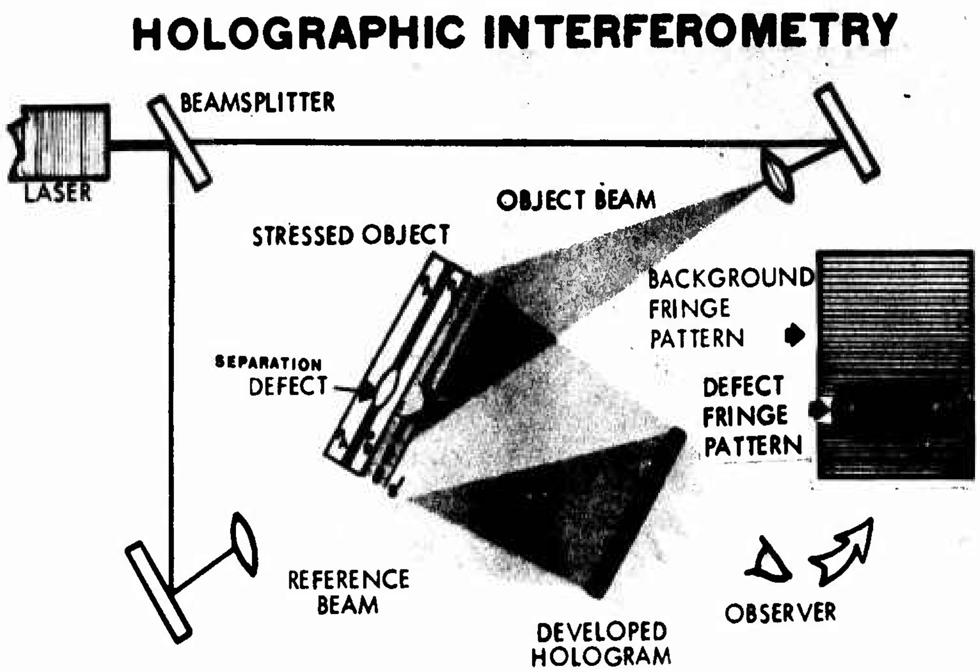


FIGURE 6
HOLOGRAPHIC INTERFEROMETRY WITH BACKGROUND AND DEFECT FRINGE PATTERN SHOWN

Figure 7 is a specific example of a fringe pattern, as seen through the hologram, along with the corresponding tire anomolies located.

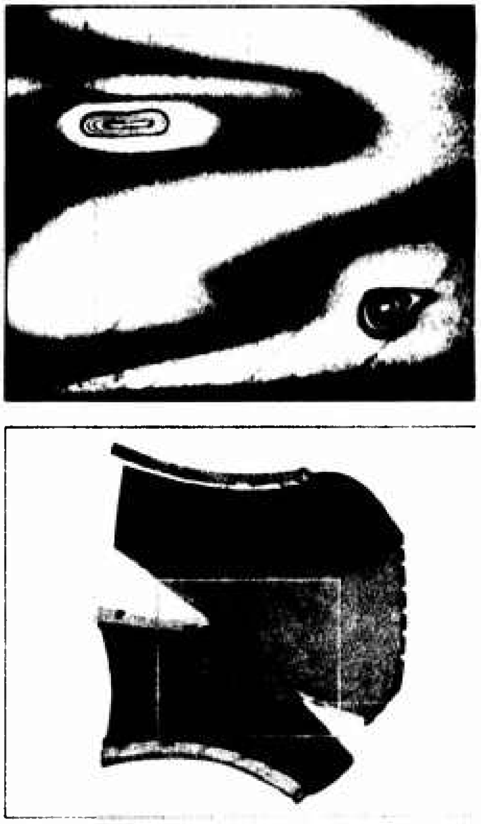


FIGURE 7
FRINGE PATTERN WITH IRREGULARITIES AS SEEN THROUGH THE HOLOGRAM

EQUIPMENT AND TECHNIQUE

When studying the propagation of inner ply separations in truck tires for the purpose of understanding failure mechanisms, in specific tire constructions, the tire is holographed when new and then again at various mileages. New or used, the tire is tested in the unmounted (unrimmed) configuration which is shown in Figure 3A and 3B.

Note in the photographs that the vertical steel posts (for more detail see Figure 8) are used to spread the beads of the tire. Bead spreading is necessary to provide a bead to bead, top to bottom, view of the tire.

Without the spreaders the beads would obscure part of the camera's view. The tire is tested 90° or one quadrant at a time, hence a given test is made over 90 circumferential degrees and from bottom to the top bead as will be shown in more detail later. The test is then repeated four times by rotating the tire four times on a merry-go-round style turntable platform. Four separate tests are made, one for each quadrant resulting in four film frames.

TIRE PREPARATION

To originally prepare the tire for testing, it is placed in a spreader (Figure 9A) and the spreader posts shown hanging on the wall are inserted into the tire. The tire is then lightly dusted with a white powder or paint to enhance the reflection of light from the inner surface. Crown marks may be placed inside the tire (Figure 9B) if desired for later position reference in the hologram. The tire is then taken (Figure 9C) to the machine (Figure 9D) and lifted into position (Figure 9E) where it is now ready for testing (Figure 9F).

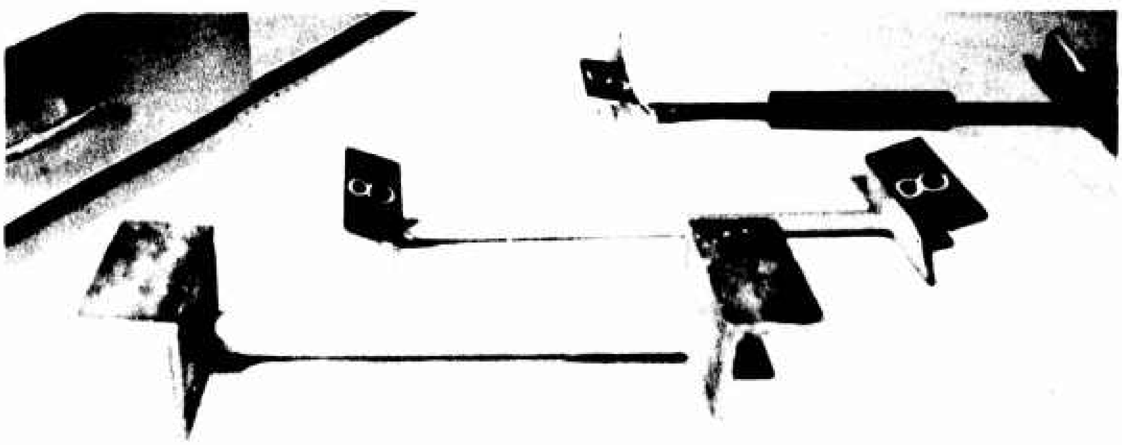


FIGURE 8
INDIVIDUAL SPREADER POSTS

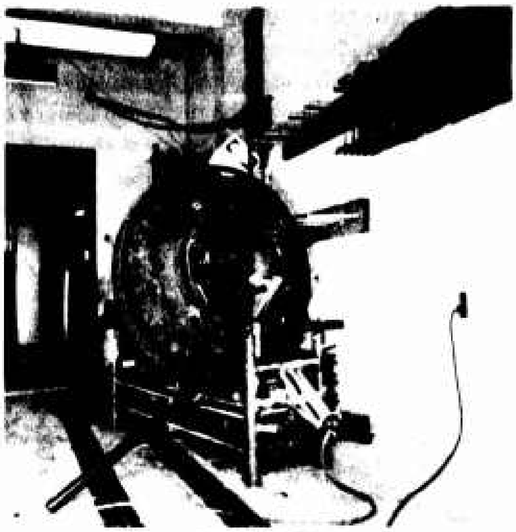


FIGURE 9A

FIGURE 9B

FIGURE 9C

FIGURE 9D

FIGURE 9E

FIGURE 9F

TEST SEQUENCE

The complete test sequence, which takes about four minutes, is automatic and proceeds as follows. The dome on the machine is lowered (Figure 10A) by activating the automatic start button on the control console (Figure 10B). An exposure is made in the no vacuum condition in quadrant one. A vacuum is then pulled and after a brief pause a second exposure is made on the same film frame. The film is now advanced and the merry-go-round turntable rotates the tire to quadrant two. After all four quadrants are completed, where each quadrant has taken a little under one minute, the dome raises and the machine is ready for reloading.

After running from 20 to 40 tires, depending upon the film frame size selected, the 70 mm roll film is removed, developed (Figure 10C) and viewed (Figure 10D) at a reading station. Suppose that the tire tested in our example run contained a separation in the lower shoulder region of the tire. Upon looking in the film viewer at the hologram one would see the separation denoted by, SEP, in Figure 10E. The background fringes reveal the average strength of the carcass, whereas the sharp elliptical fringes reveal the presence and exact outline of a separation as exhibited in Figure 10F. Note also the location where the tire was cut, as exhibited in Figure 10E.

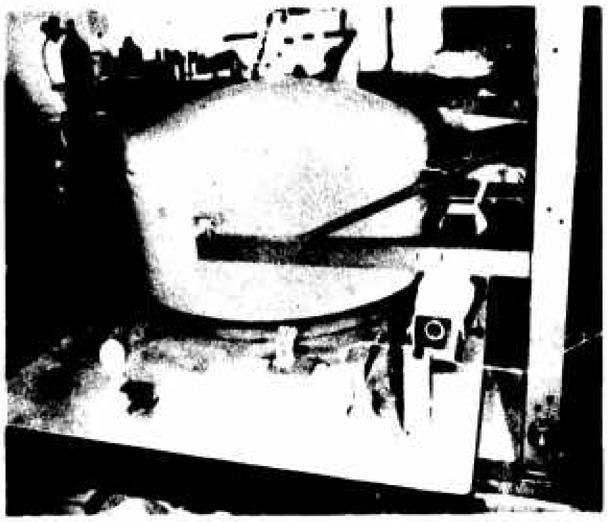


FIGURE 10A

FIGURE 10B

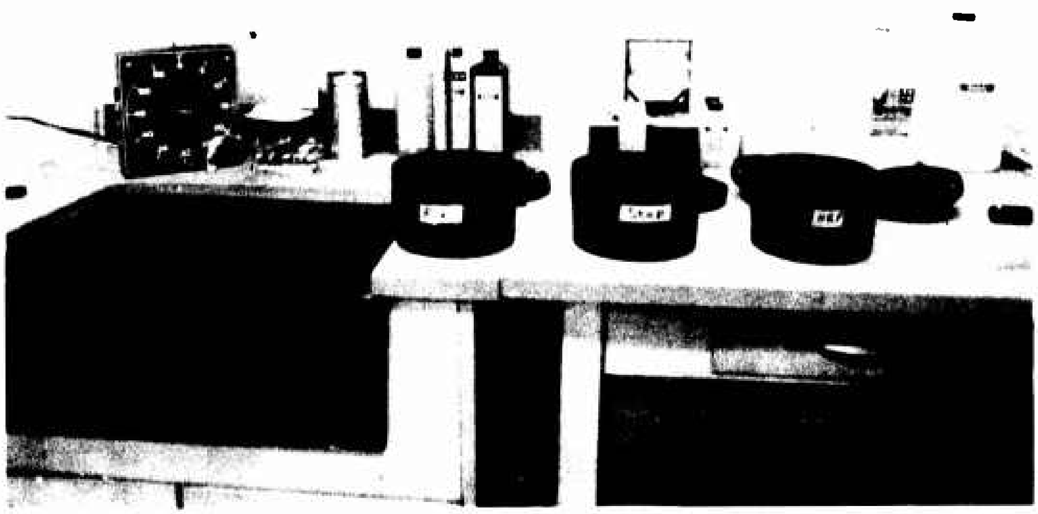


FIGURE 10C

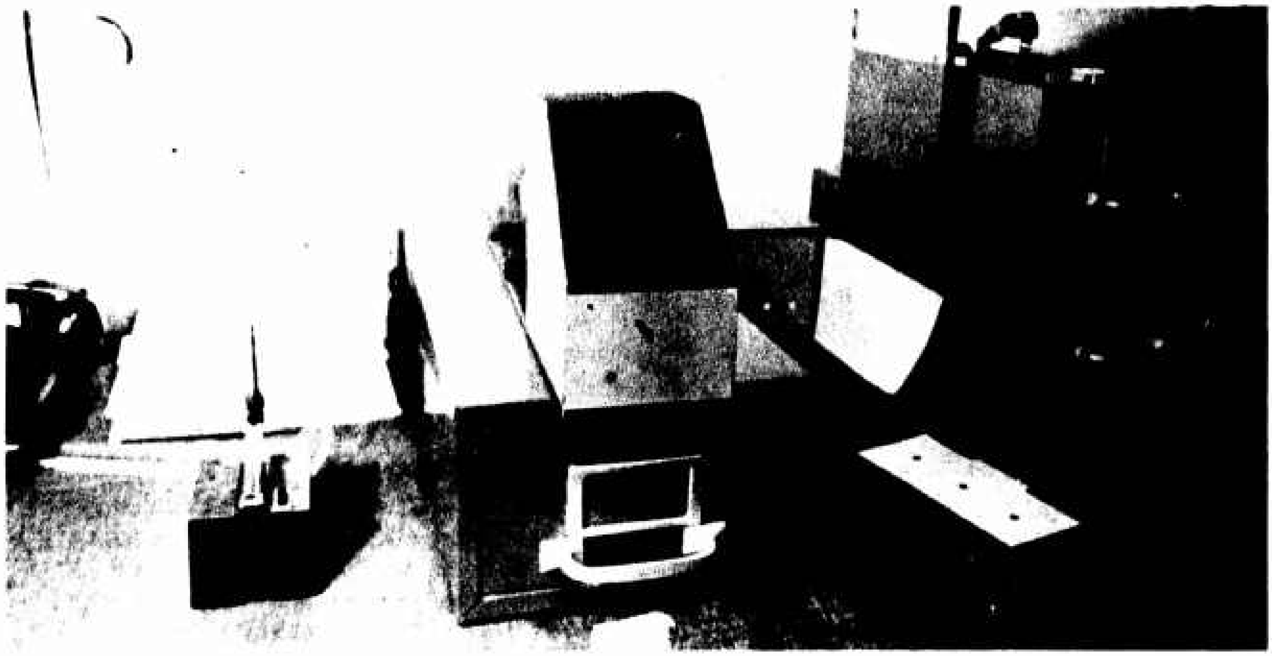


FIGURE 10D

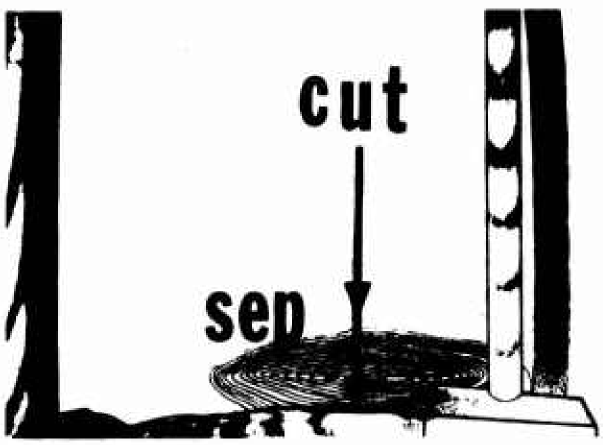


FIGURE 10E

FIGURE 10F

TIRE SELECTION AND ROAD TESTS

Before discussing some specific results of the propagation of separations in truck tires, a brief comment should be made about the selection of tires and subsequent fleet operations (road tests). Typically a group of from 100 to 200 (preferably upwards to 200 for good statistical results) truck tires of a given size and construction are randomly chosen by the manufacturer. The original tires, with no mileage, are holographed, H_0, and then mounted on fleet truck (Figure 11).

Thereafter the tire is dismounted at various increments of mileage and reholographed. The first reholograph, H_1, is typically taken at about 20,000 to 30,000 miles, unless the tire contains large defects. The tire is then remounted to obtain additional mileage. The second reholograph, H_2, is typically taken at 40,000 to 60,000 miles and the third, H_3, at 60,000 to 90,000 miles. If the original tire contained large separations, the data is obtained by running the tire on an indoor test wheel. This process is continued until the tire wears out, is removed due to excessive propagation of separations or actually fails. The tires with poor structural integrity (containing) inner ply separations, poor uniformity, etc.) are not run on vehicles as a single group. We run a complete group, as they would normally come from the manufacturer. The majority of the tires in the group provide us with statistical control information. In other words, we want to compare the performance of the group or ensemble as compared to individual tires within the group, making sure that the general running conditions are the same for the complete group. One of our objectives is the observation of the performance of the tires containing separations as compared to the tires which do not contain separations. In addition, we are very much interested in the overall structural integrity of the tire as a function of mileage and performance. The details of the tire selection and running procedures are very involved, and hence will not be covered in this paper. However, before proceeding on to specific truck tire results, it might be instructive to review a general example of our data gathering procedure. For purpose of explaining the data gathering procedure note Figure 12 which is data taken on a J78-15 passenger tire.* Physical separation (belt edge) is shown as a function of mileage where the vehicle was driven at normal running speeds and the tire was run at recommended inflation pressures.

The original tire was tested (no mileage), resulting in holographic film – H_0, which revealed a ¼ inch belt edge separation. The tire was then mounted and run 1000 miles on the vehicle. The tire was then dismounted and the first reholograph was made, resulting in holographic film – H_1, which revealed the propagation of the separation as noted in the Figure 12 (H_1 reveals the first mileage data). The tire was remounted and rerun another 1000 miles, resulting in the H_2 data. The procedure is thus continued until the tire lives out its normal mileage or the tire system fails prematurely, as was the case for this tire at 7750 miles.

*We have chosen a passenger tire as a data example only because the test repetition is high and hence a better idea is presented of the typical data gathering procedure. We usually obtain only two data points on a truck tire after the original holograph: whereas on passenger tires, we may get up to 10 and on aircraft up to 5 or 6.

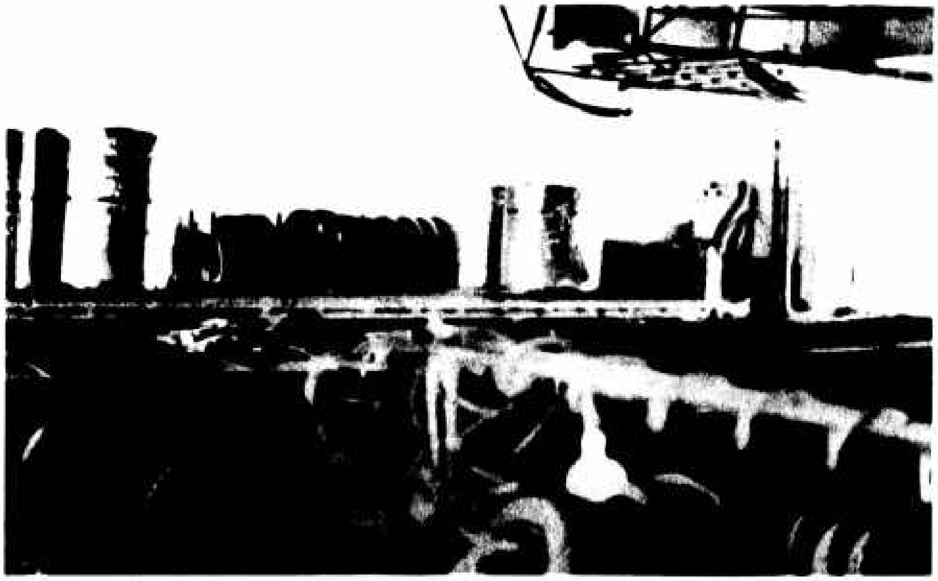
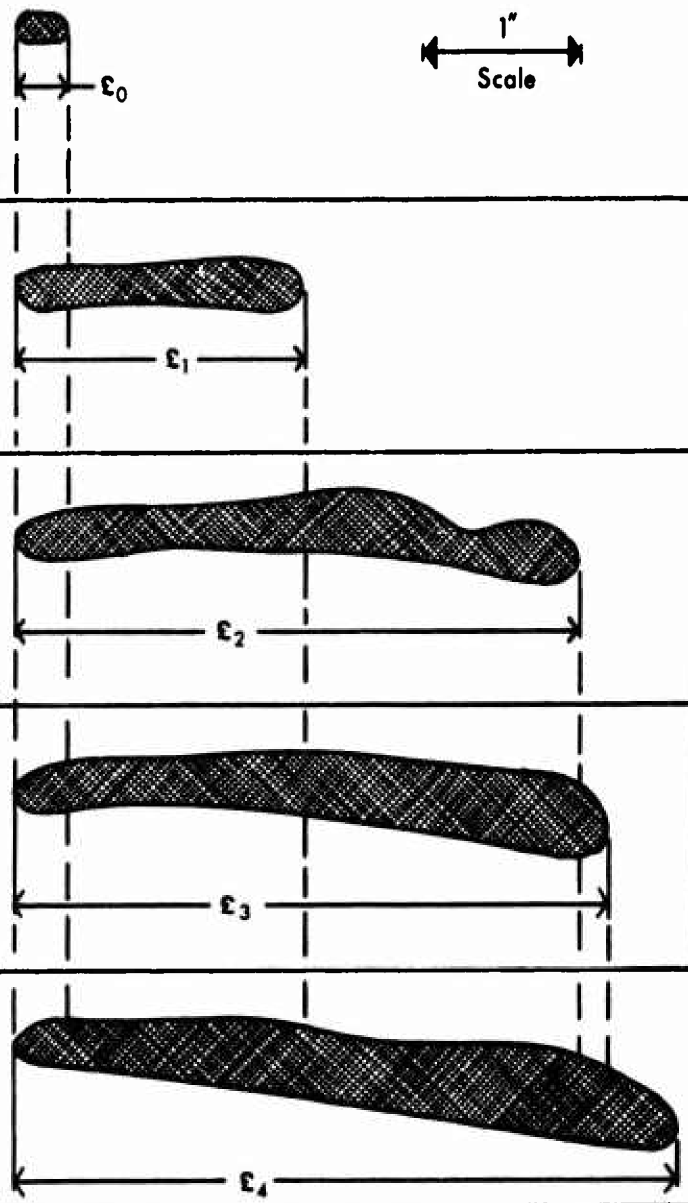


FIGURE 11
TIRE MOUNTING ON FLEET TRUCKS



PHYSICAL SEPARATION *	M MILEAGE	ℓ MAX. LENGTH	P. E. PERCENTAGE ELONGATION
H_0	0	1/4"	0
H_1	1000	1 3/4"	$(P.E.)_1 = \frac{\ell_1 - \ell_0}{\ell_0}$ = 700%
H_2	2000	3 3/8"	$(P.E.)_2 = \frac{\ell_2 - \ell_0}{\ell_0}$ = 1240%
H_3	4000	3 5/8"	$(P.E.)_3 = \frac{\ell_3 - \ell_0}{\ell_0}$ = 1360%
H_4	5000	4"	$(P.E.)_4 = \frac{\ell_4 - \ell_0}{\ell_0}$ = 1600%
H_5 FAILURE	7750	–	∞

*Outline taken from photograph of hologram.

FIGURE 12
EXAMPLE OF DATA GATHERING PROCEDURE PHYSICAL SEPARATION AS A FUNCTION OF MILEAGE

REPRESENTATIVE TEST RESULTS – EXAMPLES OF PROPAGATION OF PLY SEPARATION AND CORRESPONDING COMMENTS UPON RATE OF PROPAGATION

As mentioned earlier, one of the basic objectives of this paper is to provide examples of the propagation of inner ply separations in truck tires. We have observed that all separations in truck tires will propagate. A detailed analysis of this propagation is beyond the time and space limitations of this paper and will be treated in detail in a subsequent paper. Our present goal will be to show 12 representative results, keeping in mind that we have observed in hundreds of cases that all truck tire separations do propagate. This propagation is a complex function of a number of parameters: such as, tire construction, separation geometry and position in the tire, mileage, load, axle position, temperature and road conditions, etc., etc. In no single test case have we observed a separation which did not propagate when the tire was properly exercised. The second and really more important question after noting that the separations propagate is: At what rate, keeping the normal life expectancy of the tire in mind? Let us proceed with examples of propagation to provide answers to the first question: Do inner ply separations propagate? the following are examples of propagation in 10.00R20, 11.R20 and 10.00R22 truck tires with corresponding rate of propagation comments.

EXAMPLE NO. I

Our first example, a 10.00R20 truck tire, was taken from a large sample of tires of similar construction, the majority of which have performed as expected in fleet tests. An exception to the group serves as our first example. The original holograph of the tire revealed a dozen or so belt edge separations ranging in size from 1/8 inch to ¾ inch with a weak belt edge running over 8 inches in length 106° to 130° (see charts – Figure 13).

Figure 13B is a chart of quadrant, Q_1, after 47,290 miles. Note the separation growth, comparing $H_0 - Q_1$ and $H_1 - Q_1$ which are directly above and below each other for convenience of comparison. The second quadrant, Q_2, Figure 13C and 13D is much more interesting from a propagation point of view. Note in H_0, without mileage, that the belt edge is weak in addition to the presence of a ¾ inch diameter separation plus four ¼ inch separations. In Figure 13D you will note that the region between 100° and 138° failed at 47,290 miles. The probability of failure when observing H_0 is very high, due to not only the size but the distribution of the separations along a "weak" belt edge. Figures 13D and 13E reveal the growth of a ¼ in separation up to 1 inch in diameter. These separations at regions other than the region of failure certainly helped to aggravate the failure of the system. Figure 13G is a photograph of the hologram (Q_2, H_1) in the second quadrant where the failure occurred. The tire failed prematurely at approximately its half life. However, if it originally would not have contained the separation in the vicinity of 120°, the tire would, to a high degree of probability, still have failed at 30° or 300° before run out. Figure 13H is a photograph of the failed tire.

Next, we shall discuss an example where the original separation is small and the rate of propagation will probably not lead to premature failure.

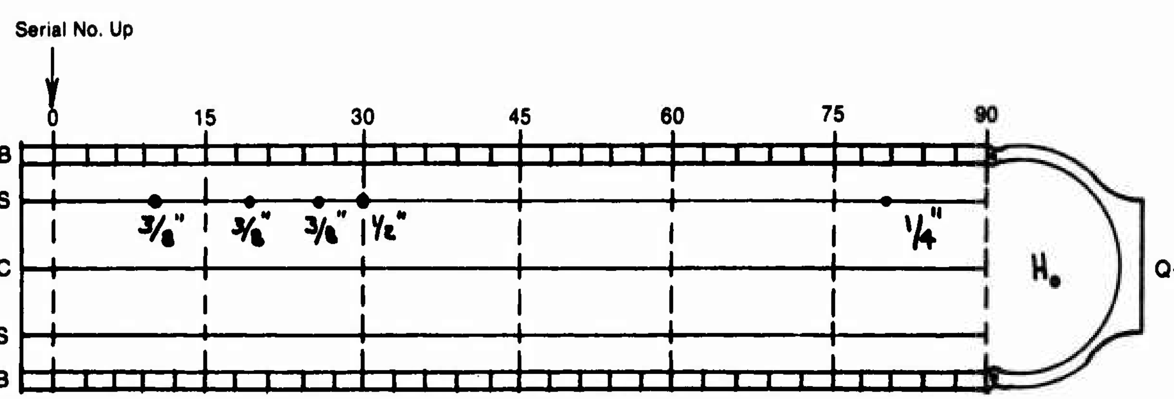


FIGURE 13A. QUADRANT ONE, NO MILEAGE – TIRE EXAMPLE NO. 1

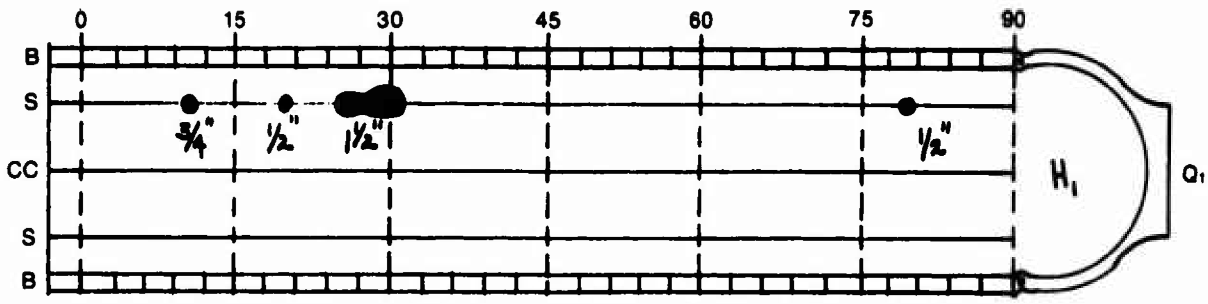


FIGURE 13B. QUADRANT ONE AFTER 47,290 MILES – TIRE EXAMPLE NO. 1

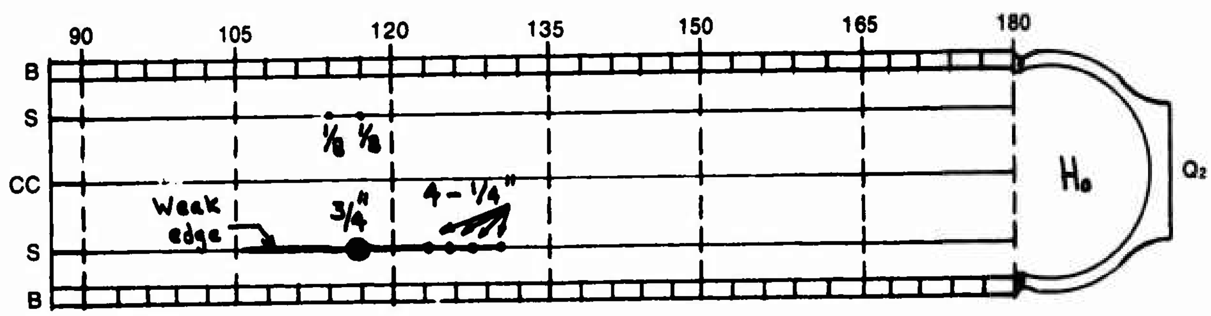


FIGURE 13C. QUADRANT TWO BEFORE MILEAGE – TIRE EXAMPLE NO. 1

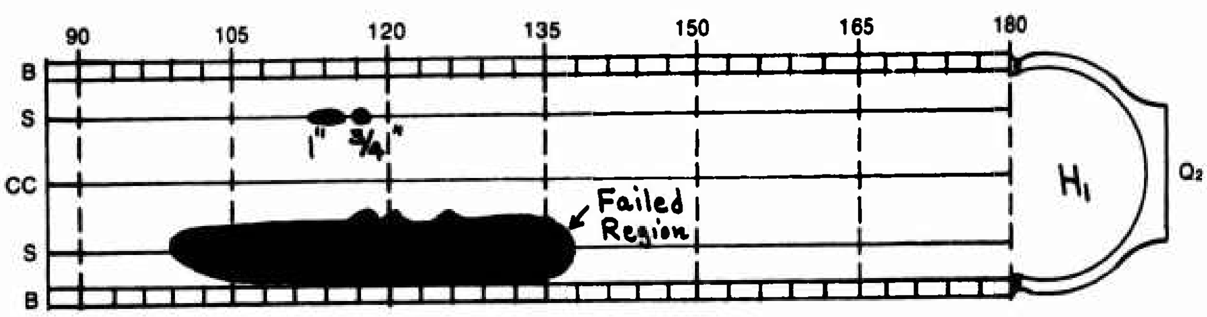
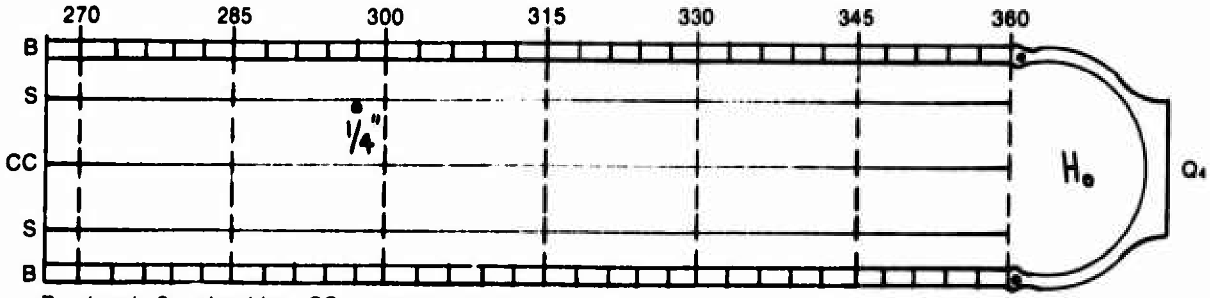
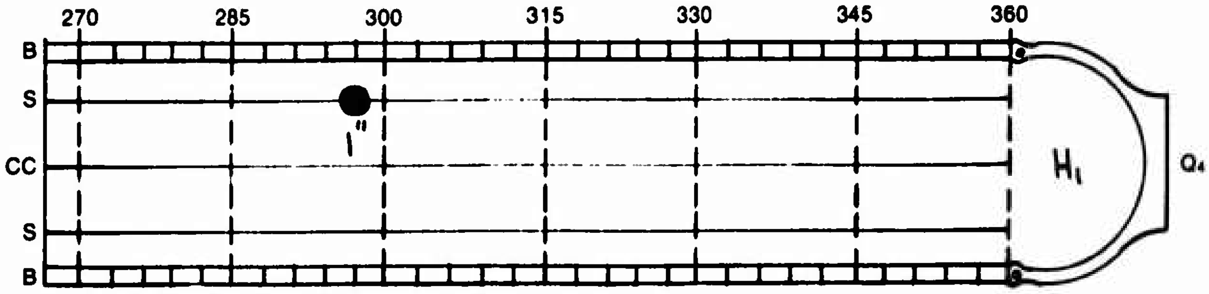


FIGURE 13D. QUADRANT TWO AFTER 47,290 MILES – SHOWING FAILED REGION – TIRE EXAMPLE NO. 1



B = bead S = shoulder CC = crown center

FIGURE 13E. QUADRANT FOUR, NO MILEAGE – TIRE EXAMPLE NO. I



B = bead S = shoulder CC = crown center

FIGURE 13F. QUADRANT FCUR, AFTER 47,290 MILES – TIRE EXAMPLE NO. I

FIGURE 13G
PHOTOGRAPH OF HOLOGRAPH OF FAILED TIRE — QUADRANT TWO

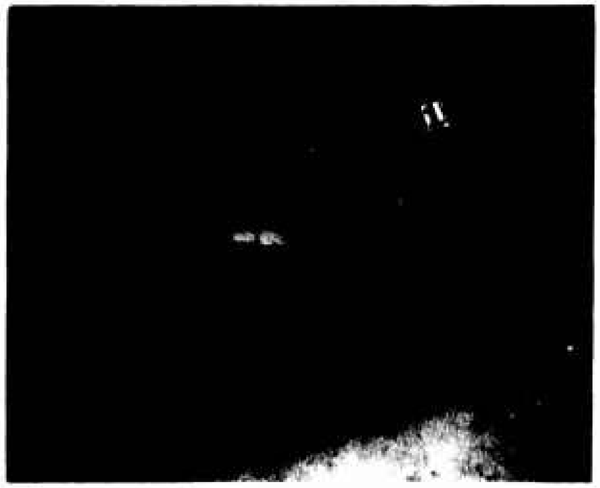


FIGURE 13H
PHOTOGRAPH OF FAILED TIRE

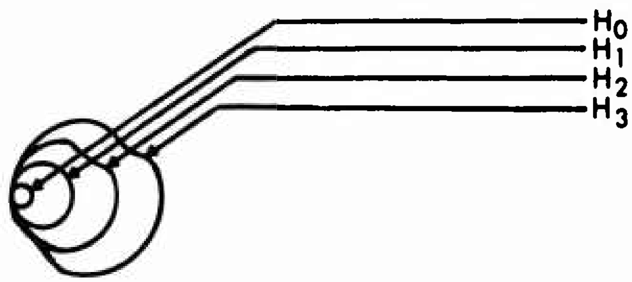
EXAMPLE NO. II

The history of example No. II is summarized in Figure 14, which is a tracing of the physical area separated (taken from the photographs of the holograms H_0 through H_3) as a function of road mileage in a radial bus tire. The original holograph of this radial bus tire revealed that the tire possessed excellent structural integrity, evidenced by the fact that the holographic fringe lines in the tire were highly uniform. There was, however, a 1/8 inch diameter crown separation at 282°.

One immediately asks the question: Could such a small separation, due to its propagation, possibly grow to a size where it could lead to a failure? One would certainly not expect it to. At 30,746 miles the ratio of the area separated is ten times greater than it was before the tire had any mileage on it and yet, as evidenced by the size of the separation (3/8 inch dia.) in Figure 14, the separation still appears to be quite harmless. At 59,211 miles H_2 reveals that the ratio of area separated between H_2 and H_1 is about 3. However, the separation, which is now almost one-third of a square inch in area (5/8 inch dia.) is just beginning to cause us to begin to pay attention to it. It is important to note that the region surrounding the H_2 separation is still very strong and does not appear to have degraded to any appreciable extent. The tire was dismounted and examined again at 94,217 miles. The area has now increased to 0.6 inch square, where $A_3/A_2 = 2$ and the overall diameter has reached 7/8 inch ± 1/8 inch.

The structural integrity of the balance of the tire is still excellent. I would expect this tire to run to the recap stage with relatively low probability of failure. It would appear, based on this example, that separations in the vicinity of 1/8 inch diameter in the original tire, despite an interesting growth pattern, will not lead to failure prior to run out.

Before proceeding to another example where the original separations are larger and invariably do lead to failure, a brief comment might be made about the direction of propagation. As a general rule propagation is in a direction opposite wheel rotation direction, provided the separation falls within the foot-print width of the tire.



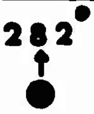
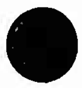
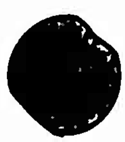
PHYSICAL SEPARATION Scale 1"	MILEAGE	ACTUAL AREA in.^{2}	RATIO OF SEPARATION AREA
282°  H_0	0	0.01±.005	—
 H_1	30,746	0.11 ±.01	$\frac{A_1}{A_0} = 10$
 H_2	59,211	0.31 ± .01	$\frac{A_2}{A_1} = 3$
 H_3	94,217	0.60 ± .01	$\frac{A_3}{A_2} = 2$

FIGURE 14
PHYSICAL AREA SEPARATED AS A FUNCTION OF MILEAGE IN A RADIAL BUS TIRE

EXAMPLE NO. III

Before proceeding to some specific details of the overall propagation of separations which were originally in the one and two inch diameter range, examine the chart in Figure 15, for an overview of the tests.

This tire, a 10.00R20, was run on an indoor test wheel under typical low speed (22 MPH) test conditions. The tire as originally holographed contained 3 very small separations (1/8 inch dia.) at 288°, 291° and 295°, respectively, and three larger separations of 2-½ inches, 1 inch and 2-½ inches at 312°, 324° and 328°. The tests were performed at the following mileages: H_0 at 0 miles, H_1 at 1892 miles, H_2 at 3901 miles and failure at 5595 miles, whereupon H_3 was obtained.

The original defects would lead one to suspect a premature failure in this tire. Aside from the stabilizer ply separations in quadrant four, mentioned above, the structural integrity of the tire in quadrants one, two and three was quite good.

The charting in Figure 16A has the original separations marked out in black. The tire failed on the indoor test wheel at about one-half of its normal life expectancy. The extensive area separated (outlined by a dotted line) at failure is shown in Figure 16A. It is of interest to note that H_2 revealed at 3901 miles that the tire was rapidly coming apart. At this mileage new belt edge separations have been induced both to the left and to the right of the original defects, examples of which can be seen in Figures 15B and 15C.

This newly induced belt edge separation extended over 50% of the circumference of the tire at about 40% of the normal life expectancy of the carcass. At final failure the tire was massively separated at belt edge positions which were newly induced in the tire due to the orignal separations, as can be noted in Figures 15D and 15E. It was quite clear from the data gathered that the terminal belt separations caused new separations to be induced which in turn propagated very rapidly during the final stages of run out.

We will now go back to some of the earlier holograms to observe the slower growth of separations which occurred during the early stages.

Figure 15F is a photograph of hologram H_0 between 310° and 330° with corresponding separations at A, B, and C drawn on a 1 inch square grid. Note that separation A_0, which occurred in hologram H_0, is just over 2 inches in length with its center at 312°. Separation B_0 in hologram H_0 is approximately 1 inch in diameter and occurs at 324°. Separation C_0 is at approximately 327° and is 2-½ inches in diameter. These three separations constitute the only lack of structural integrity in this tire example with the possible exception of some degree of weakness along the upper breaker edge approximately 300° to 340°. The tire was next remounted and run for an additional 1892 miles. Figure 15G is a photograph of hologram H_1 between 310° and 340° with corresponding propagation of separations A and B, drawn on a 1 inch square grid. The propagation, although minor in separation A_1, is immediately evident in the grid. Likewise the propagation in separation B_1 is also evident in the grid in Figure 15G which compares the size of separation B_0 to B_1. In addition it can be noted in the photograph in Figure 15G that a minor amount of weakness is beginning to develop just to the left of A_1 and to the right of B_1. This weakness can be seen in the barely visible circles, which are forming to both the left and to the right of A_1 and B_1, respectively. These regions are not separated, but possess a low relative strength.

Tire example 3, after having complete holographic test in H_1, was remounted and run to a mileage of 3901 miles. Note Figure 15H, which is a photograph of hologram H_2 between 285° and 350° with corresponding propagation of separation C, drawn on a 1 inch square grid. Separation C_2 is compared to the physical geometry of separation C_1 and correspondingly separation C_0 to point out the relative increase in size as a function of mileage from 0 miles to a total of 3901 miles. From this chart it is evident that not only are separations A and B growing appreciably, but separation C, a crown separation, is growing as well. It is also of interest to note the region in the lower left-hand corner of photograph H_2, which indicates that a belt edge separation is beginning to form in that region. This belt edge separation, as mentioned before, has undoubtedly been induced by the presence of the other separations shown in the photograph. Also notice in photograph H_1, Figure 15G that the weak region to the left of separation A_1 has now propagated into physically existing separations to the left of separation A_1 or in this case A_2 in photograph H_2. Also separations immediately to the right of B_1 have grown appreciably. The tire was cycled once again resulting in holograph H_3 and its corresponding photograph in Figure 15I. Figure 15I is a photograph of hologram H_3 between 300° and 345° with corresponding propagation of separation C, drawn on a 1 inch square grid. In Figure 15I, we have highlighted in the grid the propagation growth of separation C specifically. Note the growth of C_0 to C_3 from approximately 2-¼ inches in diameter to 5 inches in diameter. We also note that two additional separations have appeared as shown on the grid at 339° and 345°. Figure 15J is a further example of extended propagation of separations at the 5595 mile point. This figure is a drawing of propagation of separations A and B from photograph H_3 between 270° and 345°, drawn on a 1 inch square grid. Separations A_0 and B_0 have been drawn to scale within the grid indicating the separations which exist at H_3 for comparison purposes. Note the extended 8-inch long belt edge separation between 236° and 330°. In addition, many other individual separations have appeared at this stage, which are evident in the grid above. Interestingly enough the final failure stage, which took place at 5595 miles, did not occur in this region, which contained the original separations. Despite this fact one could say that this region has definitely failed as well. The tire was removed from the test wheel, due predominately to very large separations just to the left of this region and just to the right of this region. Undoubtedly these large separations just to the left and right were caused or brought about by the separations in the 310° to 330° region in the original holograph.

Before proceeding to another example, it is of interest to point out that the extent of separation between two specific layers is indicated by the number of fringes within the separation pattern. This point was mentioned earlier in the paper, but allow us at this point to specifically demonstrate that point. In Figure 15K you will note that the relative height of separation C_2 is twice as high or in other words is physically separated twice as much as separation C_1, where separation C_2 is evident in hologram H_2 and correspondingly C_1 is evident in hologram H_1. Note in the projected drawing above the relative height curve the fact that separation C_1 contains 5 fringes and separation C_2 contains 10 fringes indicating that the actual physical separation in C_2 was twice as great as the actual physical separation in C_1. C_1 in this comparison is approximately three inches in length whereas separation C_2 is 4-¼ inches in length.

Through the above separations A, B and C as exhibited in holograms H_0, H_1, H_2 and H_3, we have noticed an appreciable propagation in the case of each separation leading to end or bringing about the failure of the tire at 5595 miles. Much more can be said individually about these separations, however, it is the objective of this paper to point out that inner ply separations do propagate and will lead to failure, if and provided, the separations are of sufficient size when the tire is first mounted on the vehicle prior to mileage.

The rate of propagation, however, is the critical factor in predicting when the tire system will fail. In this case only two 2-½ inches and one 1 inch separations, spaced relatively speaking well apart, were able to cause the tire system to fail at not more than possibly half the life expectancy of the tire.

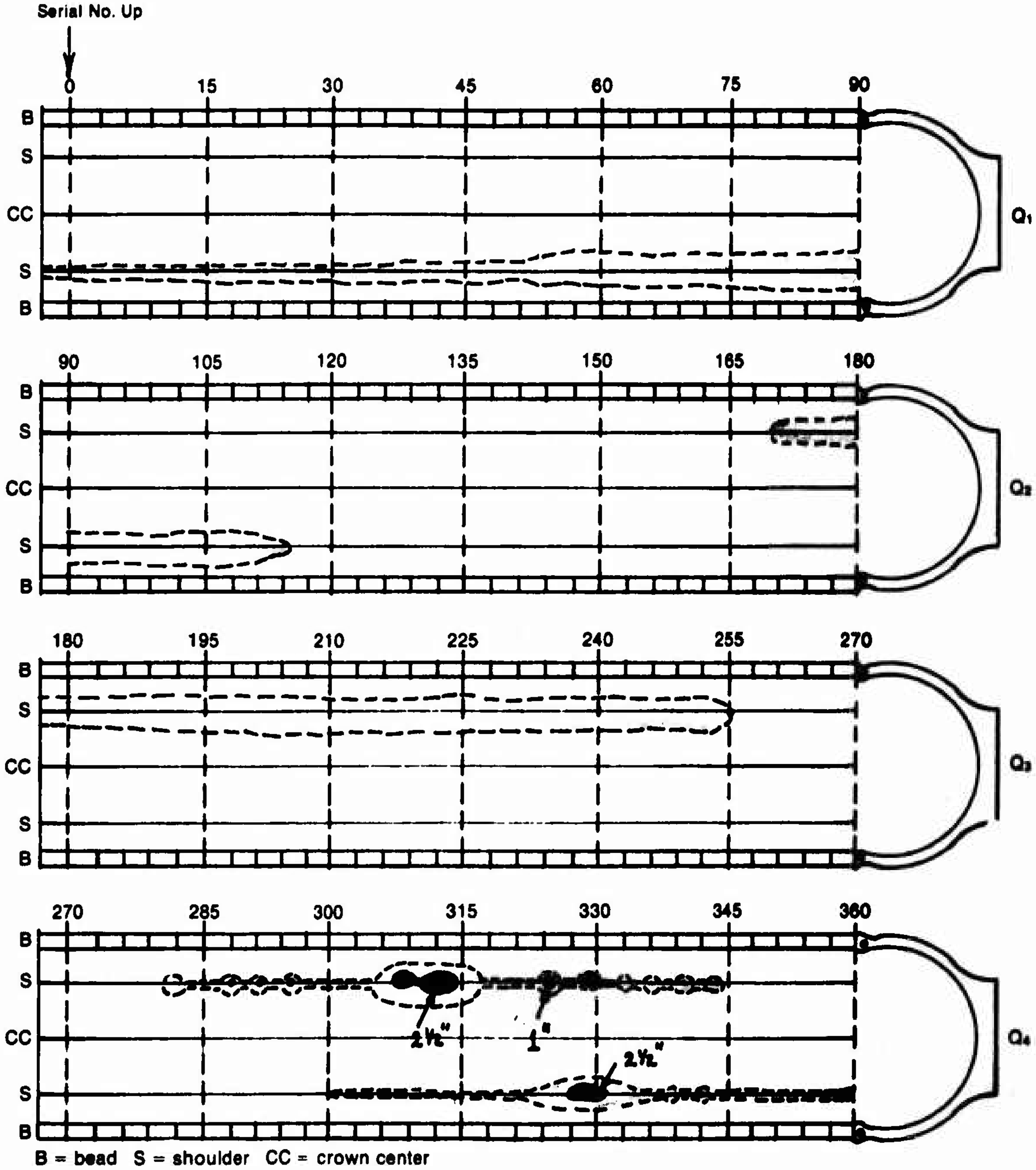


FIGURE 15A
CHART OF TIRE NO. III BEFORE AND AFTER AN INDOOR TEST WHEEL RUN OF 5595 MILES WHEREUPON THE TIRE WAS REMOVED DUE TO FAILURE

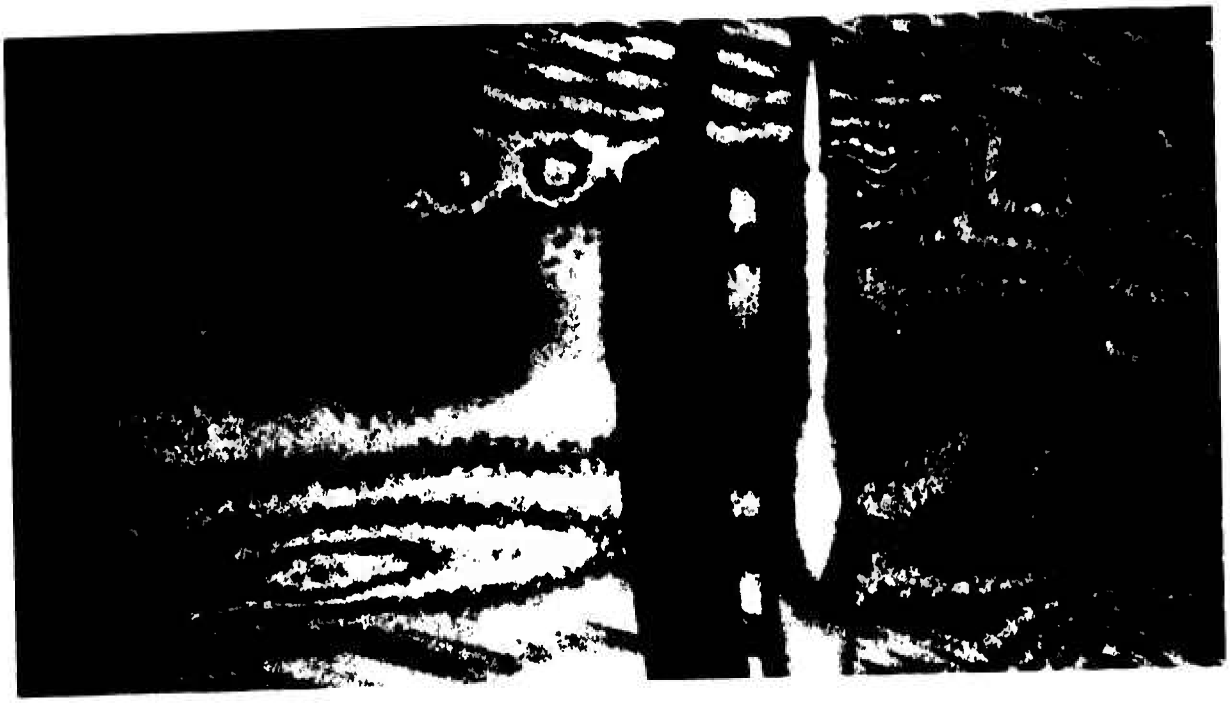


FIGURE 15B

FIGURE 15C

FIGURE 15D

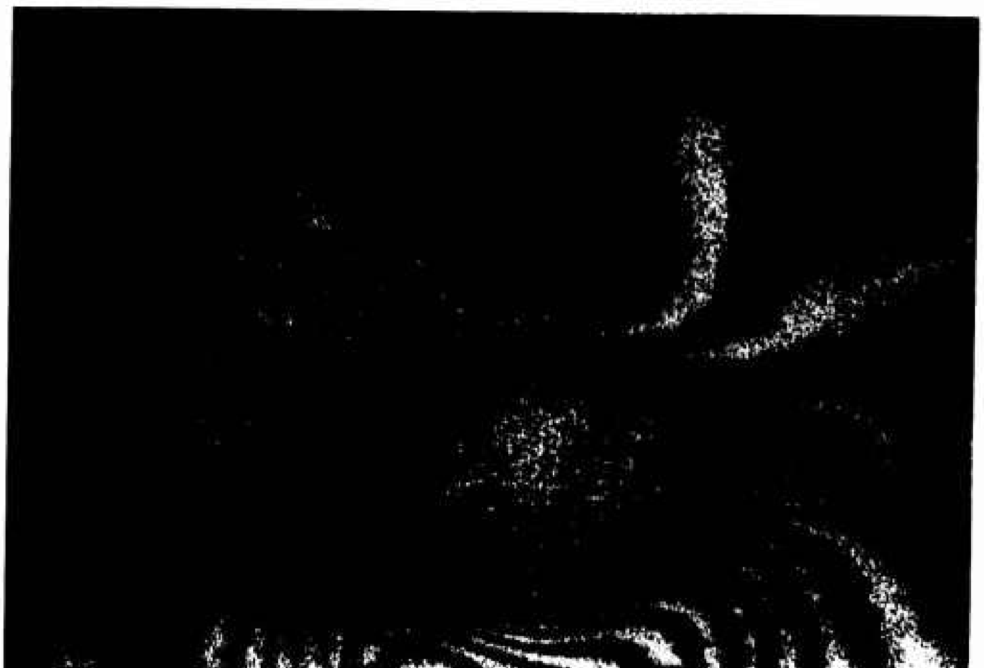


FIGURE 15E

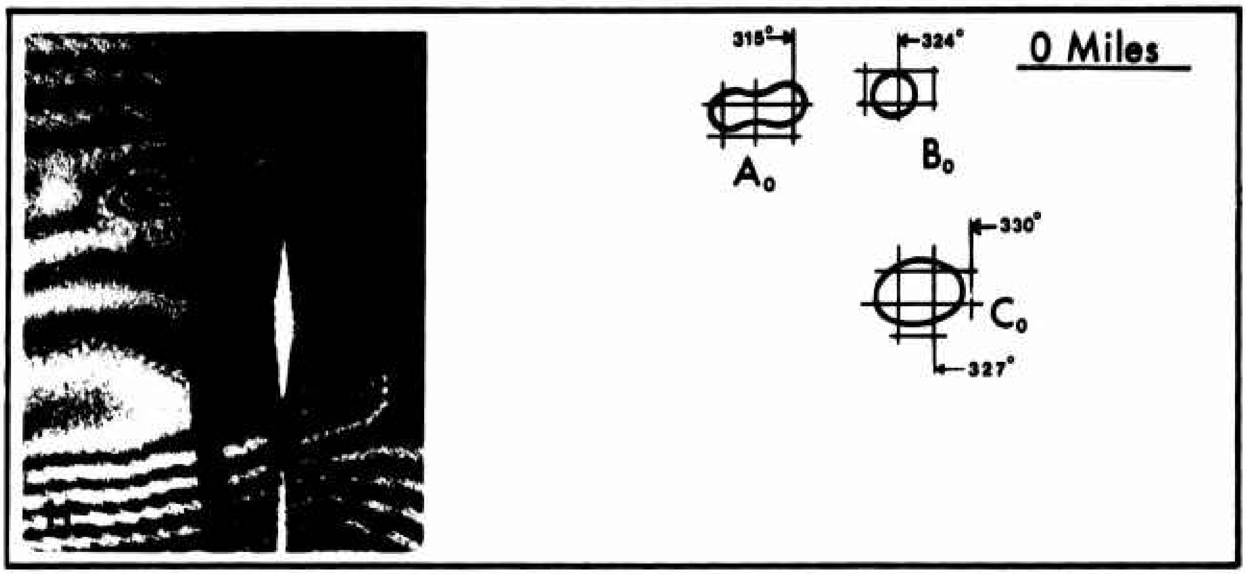


FIGURE 15F

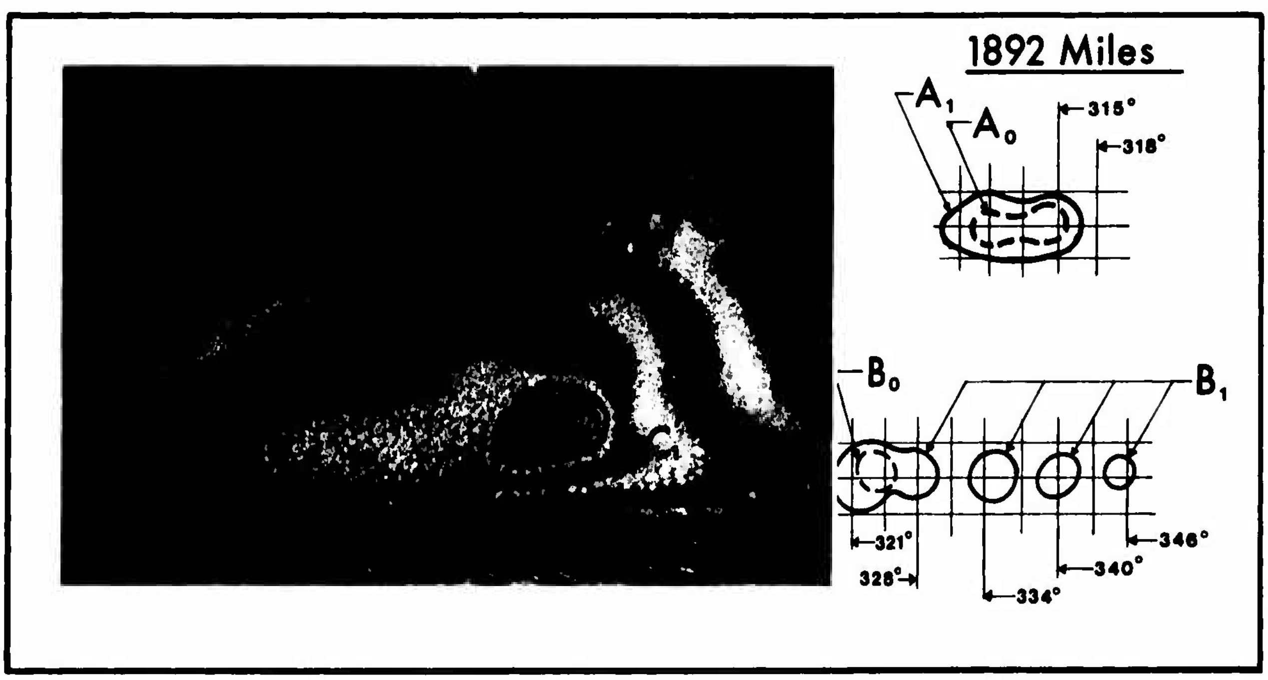


FIGURE 15G

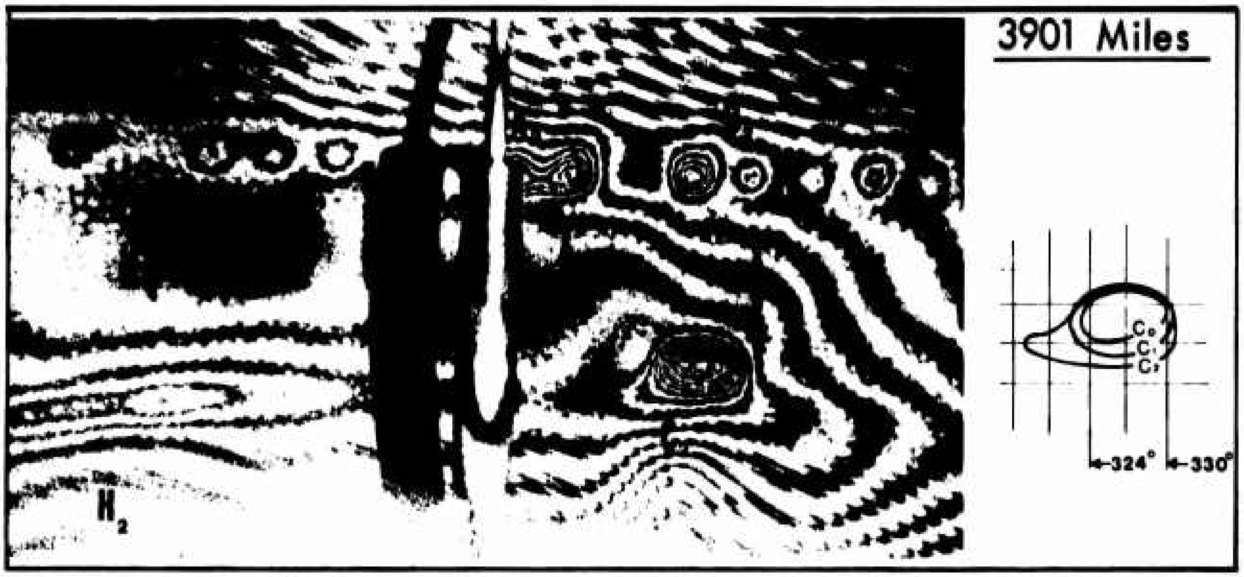


FIGURE 15H

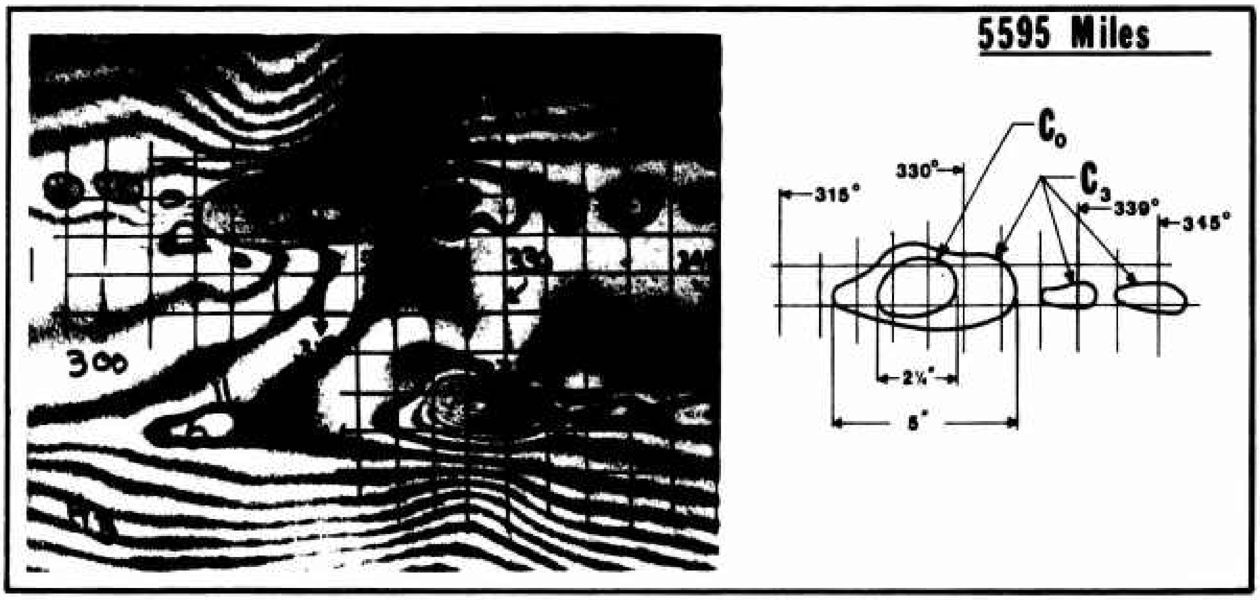


FIGURE 15I

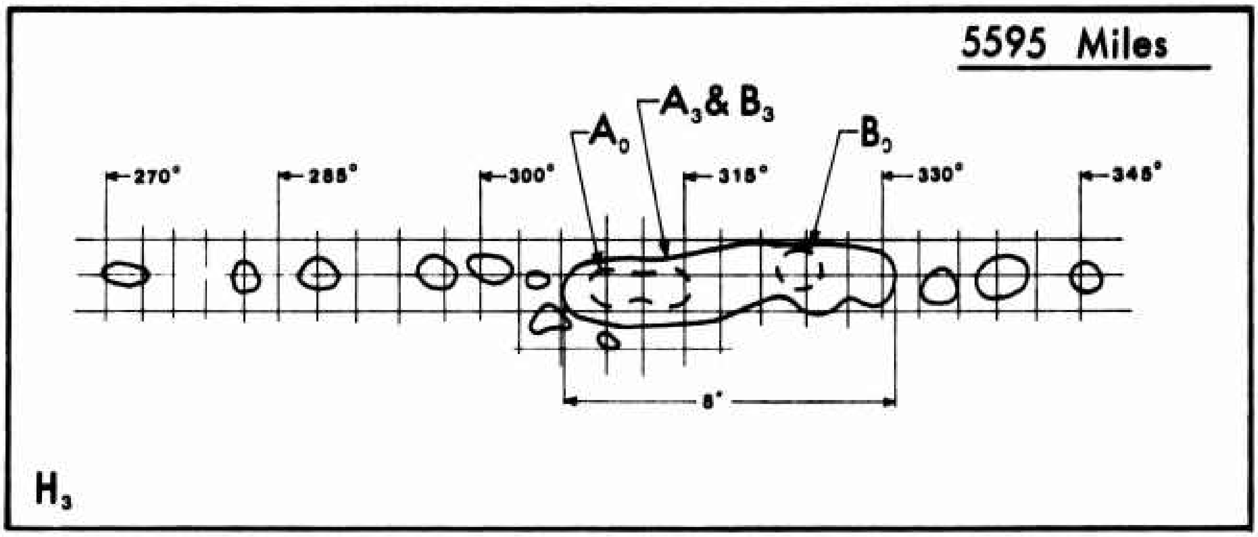


FIGURE 15J

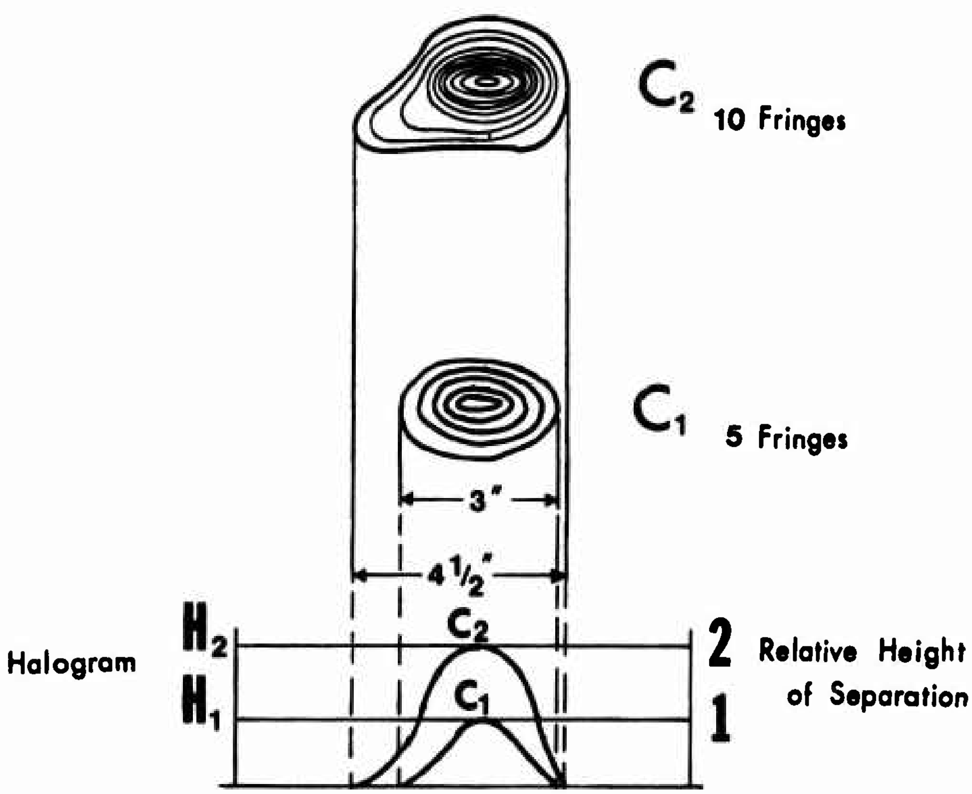


FIGURE 15K

EXAMPLE NO. IV

Our next example, a 10.00R20, which was run on a low speed indoor test wheel, failed at 5904 miles as a result of mild, but extensive separation and weakness over 25° of a lower stabilizer belt edge between 120° and 145°. The separations shown in Figure 16A when the tire was new, H_0, are represented as black dots in the figure. These separations are very interesting since the separation along the 25° span was not completely open. It consisted of a series of relatively small separations about eight (3/8 ± 1/8) inches, which were just barely open, as evidenced by the low number of fringe rings in Figure 16B – H_0, $\Delta M = 0$. During the first 1892 miles this region grew only 11% in length. However, the separations are beginning to open (there are now about eleven with an average size of (1/2 ± 1/8) inches) and join together as can be seen in H_1, $\Delta M = 1892$. On the next run of 2010 miles for a total of 3902 miles, resulting in H_2, $\Delta M = 2010$ miles in the figure, the region grew in percentage elongation by 29%.

Now the degree of separation is becoming very pronounced. The belt edge is now completely open over an inch wide from 116° through 160°. This region has been charted as a grey region with a dashed outline and is marked, H_3, in the chart in Figure 16A. In addition, separation has formed, or been further induced, at the other regions indicated on the chart. Separation, which was extensive at the time of failure (5904 miles), is shown on the chart by means of a dashed line.

Tire example IV is a particularly interesting case from the point of view of degree of separation. Independent of the fact that the original separations extended over a region of 25°, they were barely separated and the region as a whole possessed at least some amount of relative strength, as compared to a region of high strength. The region separated slowly in the beginning and then proceeded more quickly with mileage and failed at approximately half the life expectancy of similar tires with good structural integrity. Had the original separations been further open, the tire would have had a high probability of failure within the first 10 to 20% of its life expectancy. In conclusion the possession of a modest amount of strength within the separated region allowed the tire to run out to about 50% rather than 10 to 20% of its normal life expectancy.

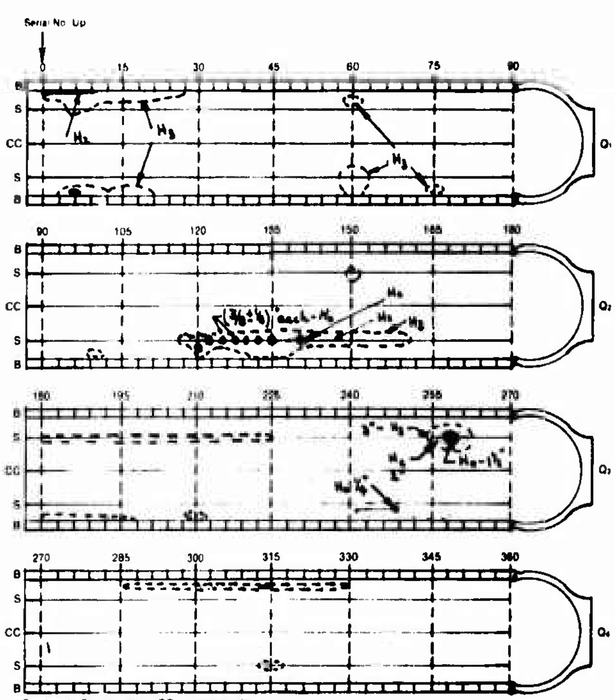


FIGURE 16A
CHART OF PROPAGATION OF SEPARATIONS OVER 360° BETWEEN H_0 AND H_3 WITH A TOTAL MILEAGE OF 5904 MILES

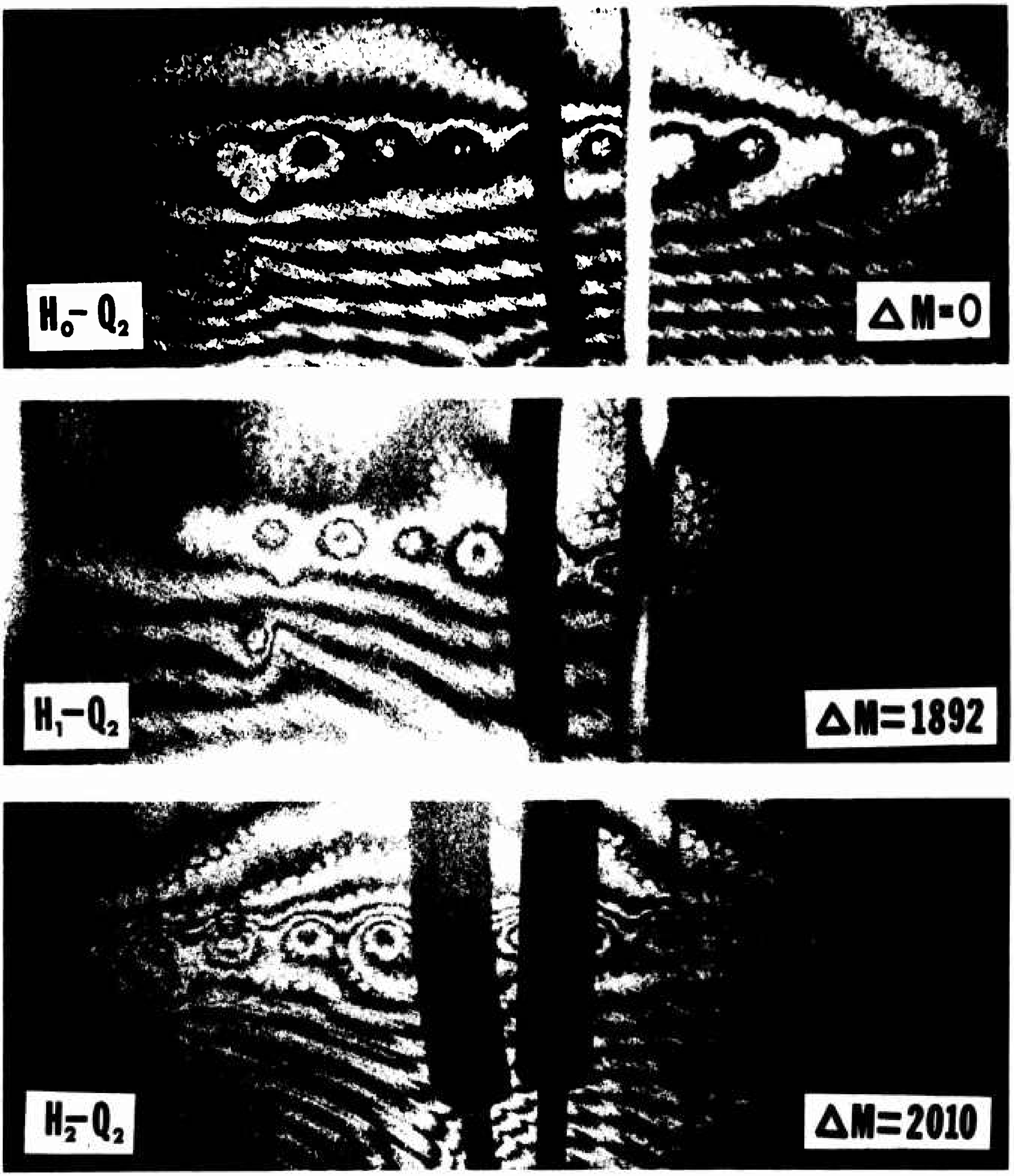


FIGURE 16B

EXAMPLE NO. V

Example V, a 10.00R22, when originally holographed revealed separation at the turnup from 148° to 159° and from 195° to 198°, as shown in Figure 17. The tire was mounted and proceeded to run on the road, whereupon it failed at 29,900 miles, due to extensive separation at the flipper or turnup edge, as shown in the chart H_1. Control tires of similar size and construction, which do not exhibit separation at the turnup or other types of separations, have performed excellently under similar road conditions.

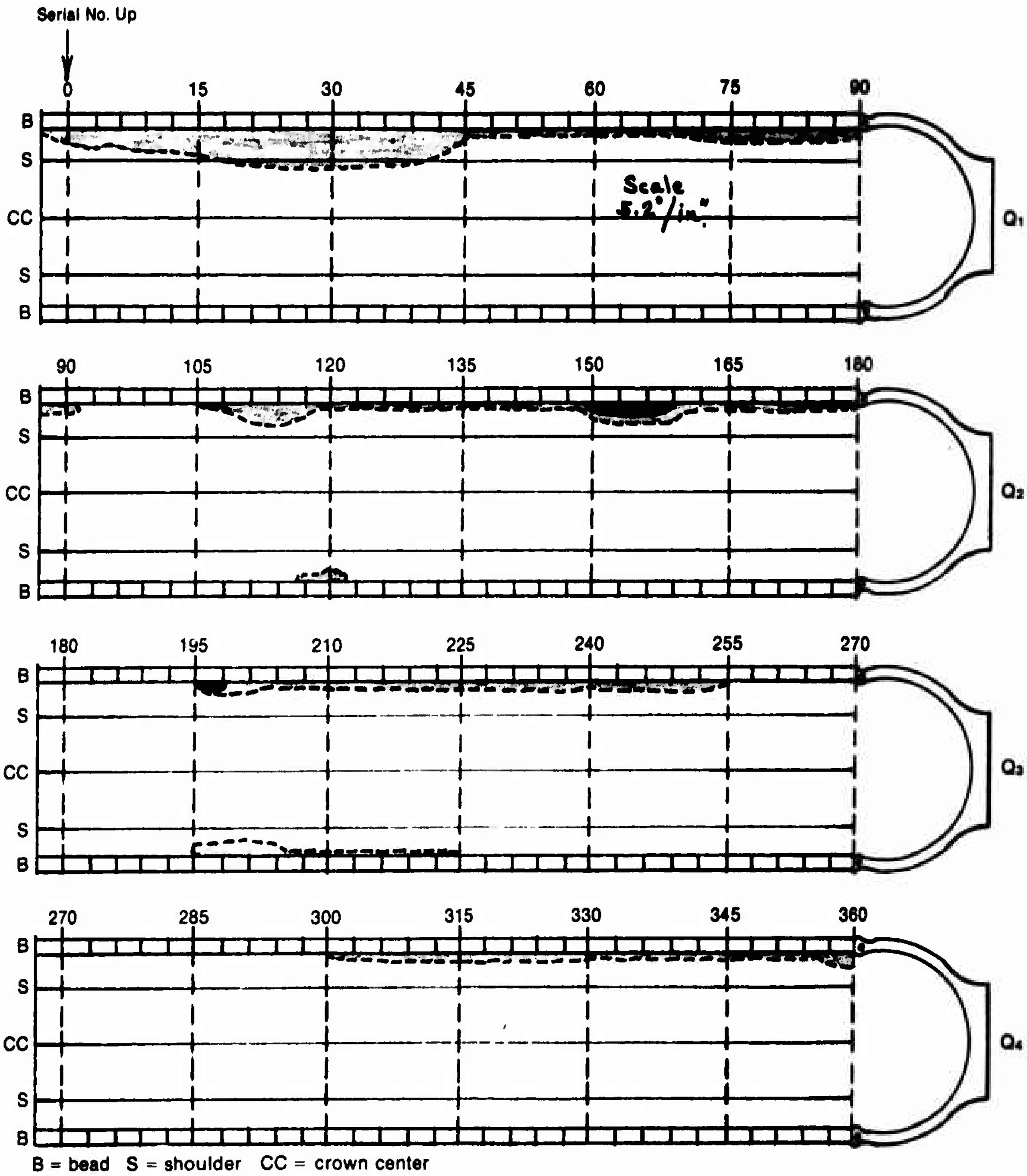
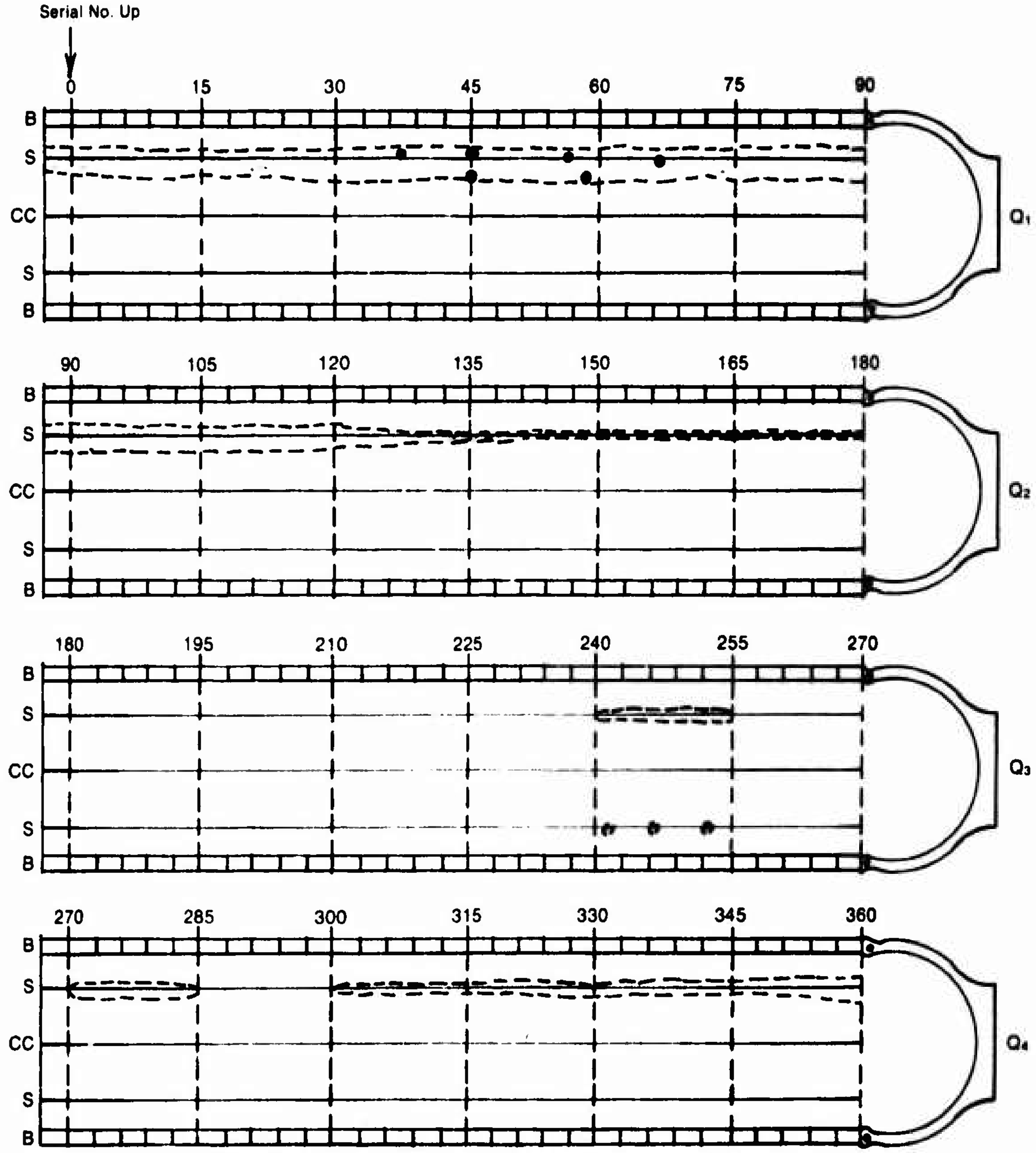


FIGURE 17
CHART OF SEPARATIONS IN TIRE EXAMPLE NO. V

EXAMPLE NO. VI

This example, a 10.00R20, which was removed "just" prior to a final failure at 56,782 road miles, is included in our list to exhibit simultaneous separation along two adjacent belt edges. The chart in Figure 18A contains both the separations at H_0 and H_1 when the tire was removed. All of the original separations (black dots), six in total, are $(1/2 \pm 1/8)$ inches in diameter with the exception of one which was $(5/8 \pm 1/8)$ inches in diameter. Four are on the outer belt edge and two are on an adjacent belt edge. Separations A, B, and C noted in H_0 by the black dots, are indicated in the failed region shown in Figure 18B. When the tire was removed, the upper belt edges were extensively separated, as shown in the chart. Whenever a cluster of separations are observed, especially when the average diameter is in the vicinity of ½ inch, premature failure is almost certain.



B = bead S = shoulder CC = crown center

FIGURE 18A
CHART OF SEPARATIONS IN TIRE EXAMPLE NO. VI

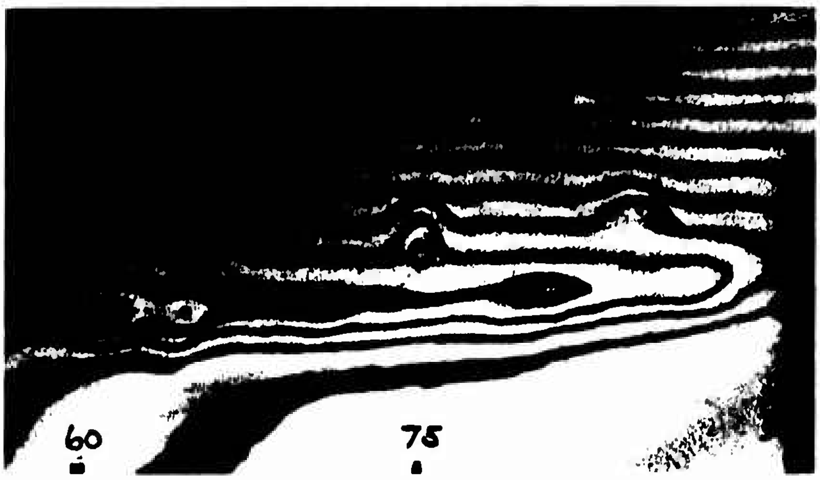


FIGURE 18B

EXAMPLE NO. VII

This tire was dismounted on a routine basis without any evidence of failure at 97,877 miles. Holograph H_1, as noted in Figure 19, revealed narrow, but extensive lower belt edge separation. The nature of the separation is shown in the photographs in Figure 20 taken in representative regions in all four quadrants (note the regions outlined by the white dots). Most of the separation is mild except for the region around $135^\circ \pm 10^\circ$, which is the location of two original, H_0, separations of $(3/4 \pm 1/8)$ inches in diameter. This region was very close to final failure. The original tire has no belt edge separation, however, it had four $(3/4 \pm 1/8)$ inch separations at 0°, 132°, 140° and 351°; in addition a very small 1/8 inch diameter one at 93°. Each of the original separations propagated to $(1 \pm 1/8)$ inches in diameter, however, all of the original ones were just barely separated and the overall quality of the tire in the area surrounding the original no mileage defects was excellent.

The tire was near failure when dismounted and yet one must not lose sight of the fact that it ran for nearly 100,000 miles. This carcass should obviously not be recapped. However, this example points out that tires containing separations can survive as long as the defects are not overly large or clustered together. On the other hand this tire could have failed at any time within the last 20,000 or 30,000 miles had it experienced a steering axle position or any form of overload. The opening of the belt edges in all probability started at the original ¾ inch diameter positions. Had even smaller separations been clustered more the probability of a premature tire removal would have been high.

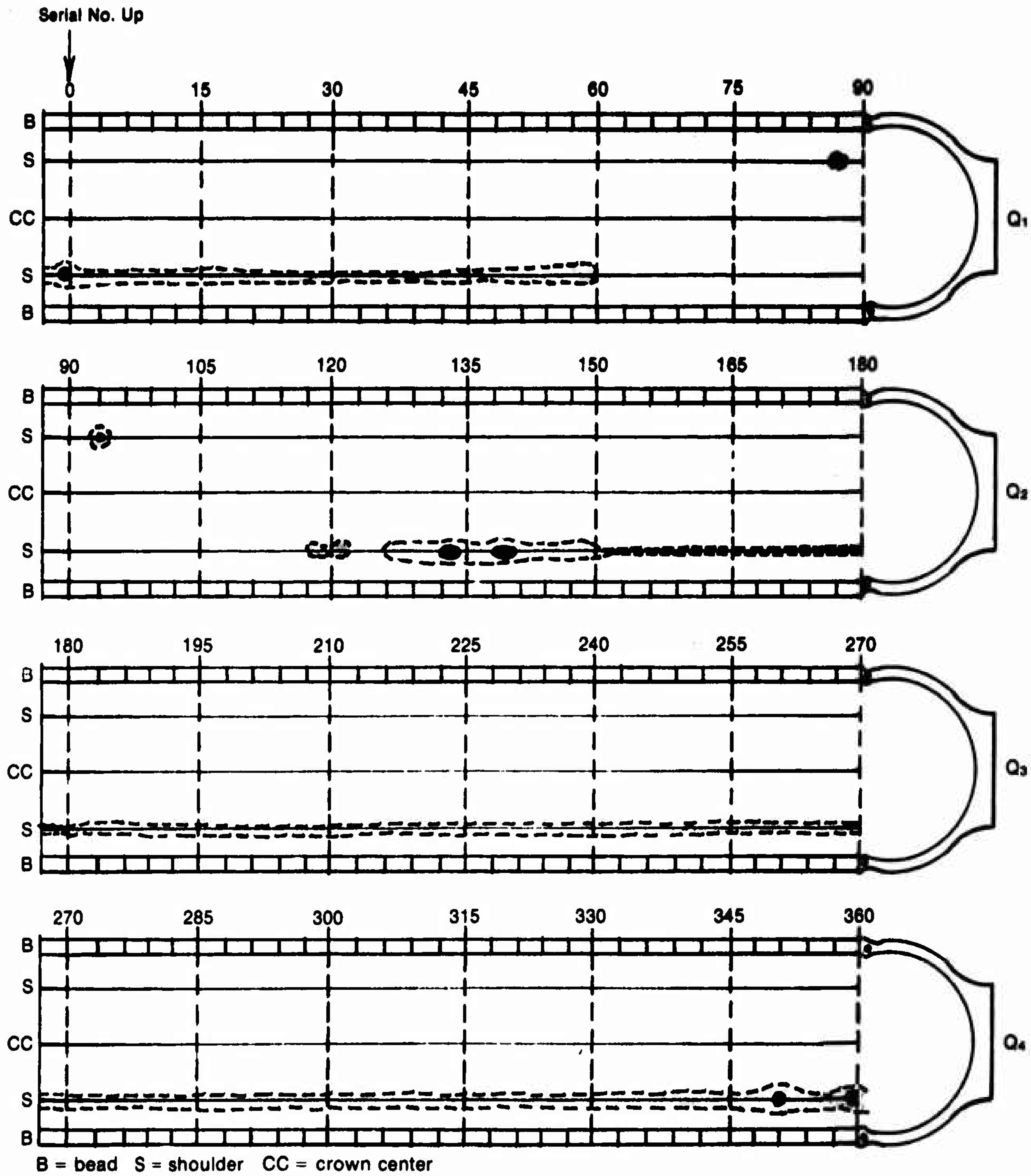


FIGURE 19
CHART OF SEPARATIONS IN TIRE EXAMPLE NO. VII

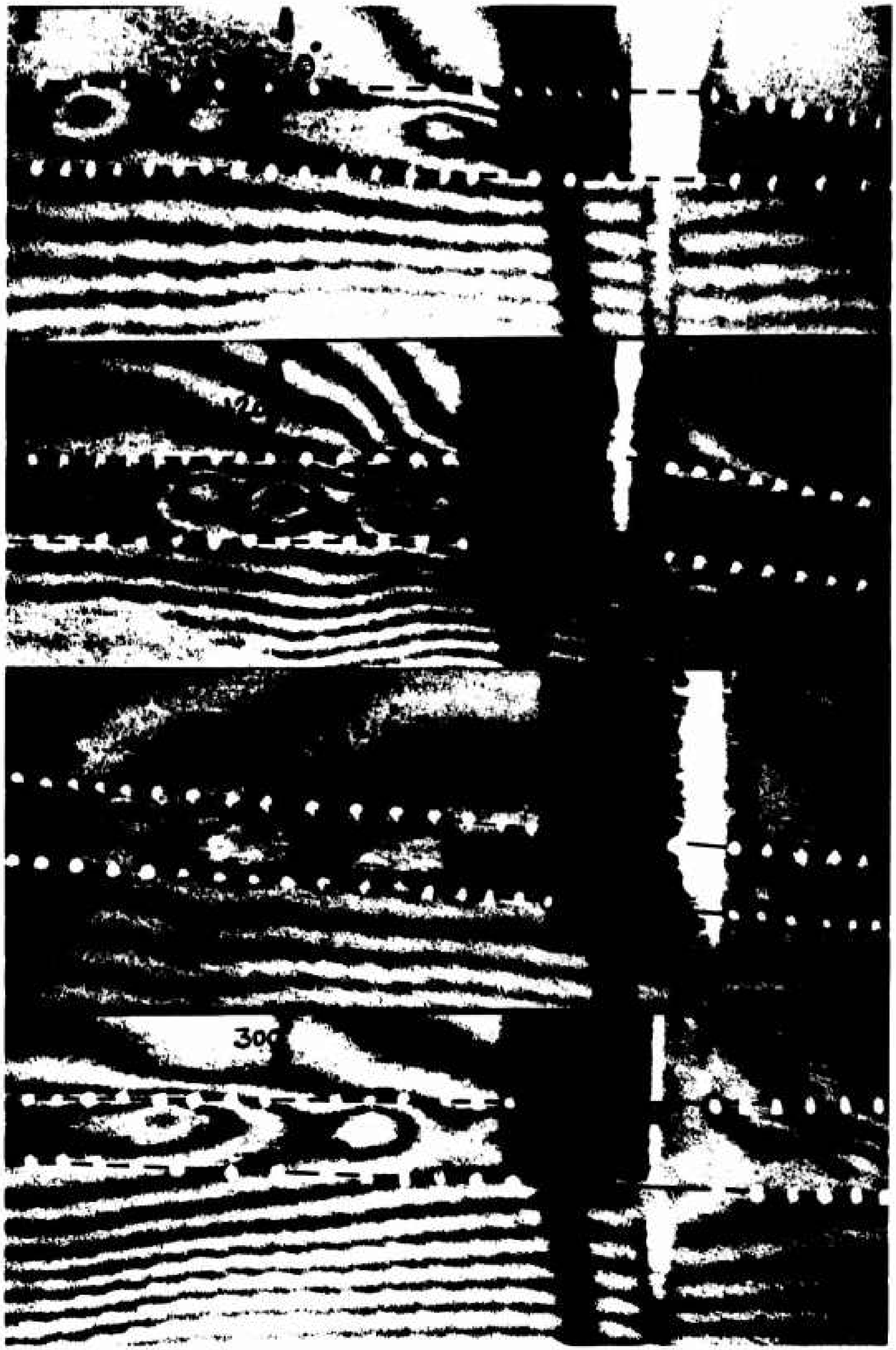


FIGURE 20
PHOTOGRAPHS OF HOLOGRAM, H_1, AFTER ROAD TEST WHERE DOTTED LINES ON PHOTOGRAPH INDICATE THE EXTENT OF THE EDGE SEPARATIONS

EXAMPLE NO. VIII

The following tire, a 10.00R20, failed prematurely in the field as shown in the chart in Figure 21 and the photograph of the failed tire in Figure 22. In this case a 1-½ inch diameter belt edge separation at 89° in the original carcass led to failure at 42,119 miles. The usual propagation took place in other defects shown. The fact that the failed region between 60° and 90° came from the original separation was quite obvious in H_1. In addition, the overall new carcass, as exhibited in H_0, was not very strong in the 60° to 90° region. The tire as a whole possessed a fair degree of structural nonuniformity. Note also that the ¼ inch and ½ inch defects at 33° and 37° grew to 1 inch and ¾ inch, respectively. The 1 inch and ½ inch defects at 105° and 315° also grew to 1-½ inches and ¾ inch, respectively.

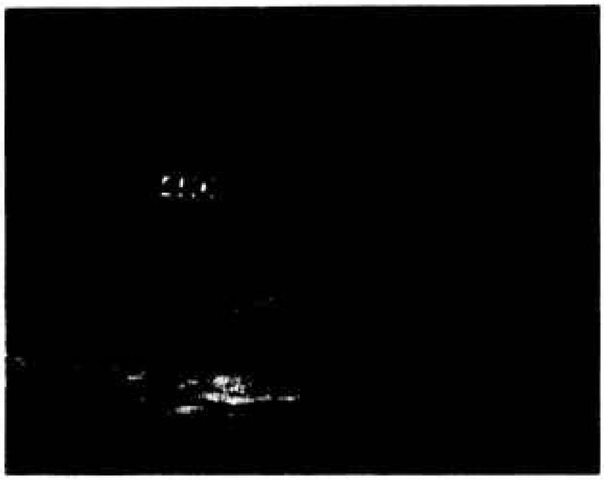


FIGURE 22
PHOTOGRAPH OF FAILED TIRE – EXAMPLE VIII

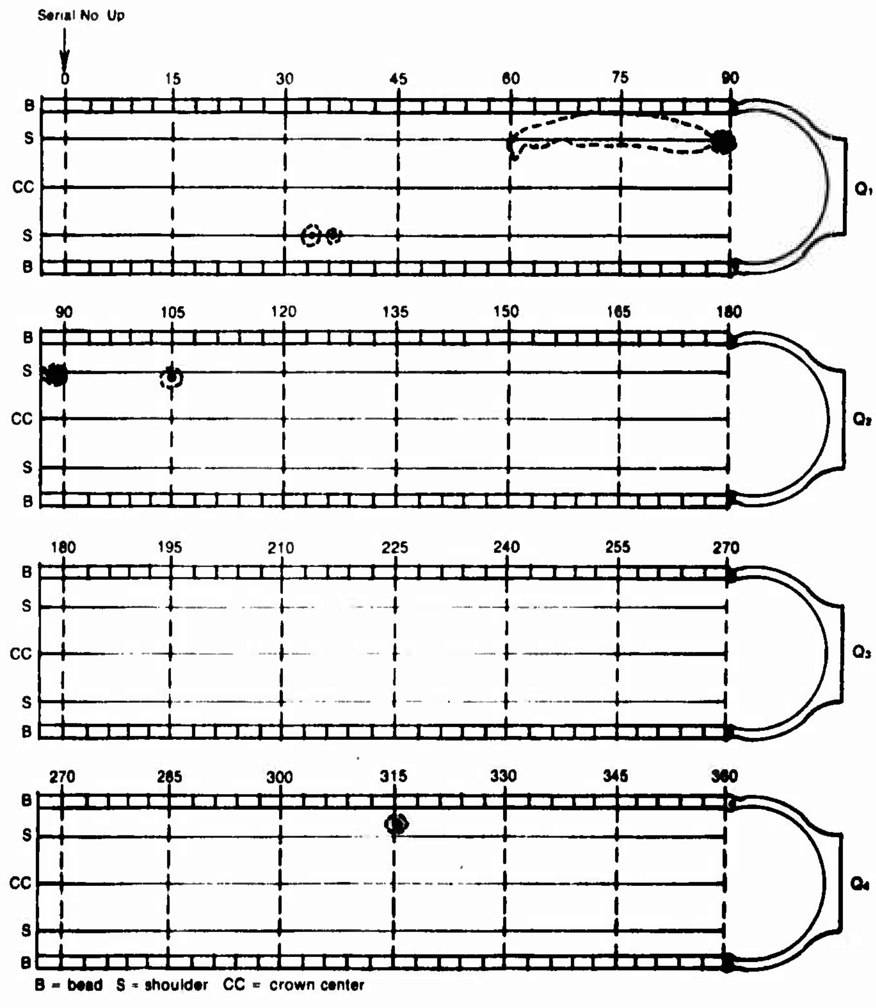


FIGURE 21
CHART OF SEPARATIONS IN TIRE EXAMPLE VIII

EXAMPLE NO. IX

Example IX, also a 10.00R20, is another case where the original tire possessed a number of very small (1/4 ± 1/8) inch separations. This tire was run for 97,877 miles before being reholographed on a routine basis. These originally small separations (note Figure 23) were not large enough to cause one to predict anything other than a very low probability of failure prior to 100,000 miles. Figure 24 is a photograph (H_1 after 97,877 miles) of five of the original ¼ inch separations which grew to an average of (1/2 ± 1/8) inch. This region is just beginning to get weak. Note that three ¼ inch ones at 120° ± 3°, which were more closely clustered, brought about a five inch separation on the upper stabilizer ply edge and the three very small ones at 198°, 203° and 208° brought about a 60° mild opening of the belt edge between 180° and 240°. Despite remaining tread depth, this tire could fail prior to total run out. The tire should obviously not be recapped.

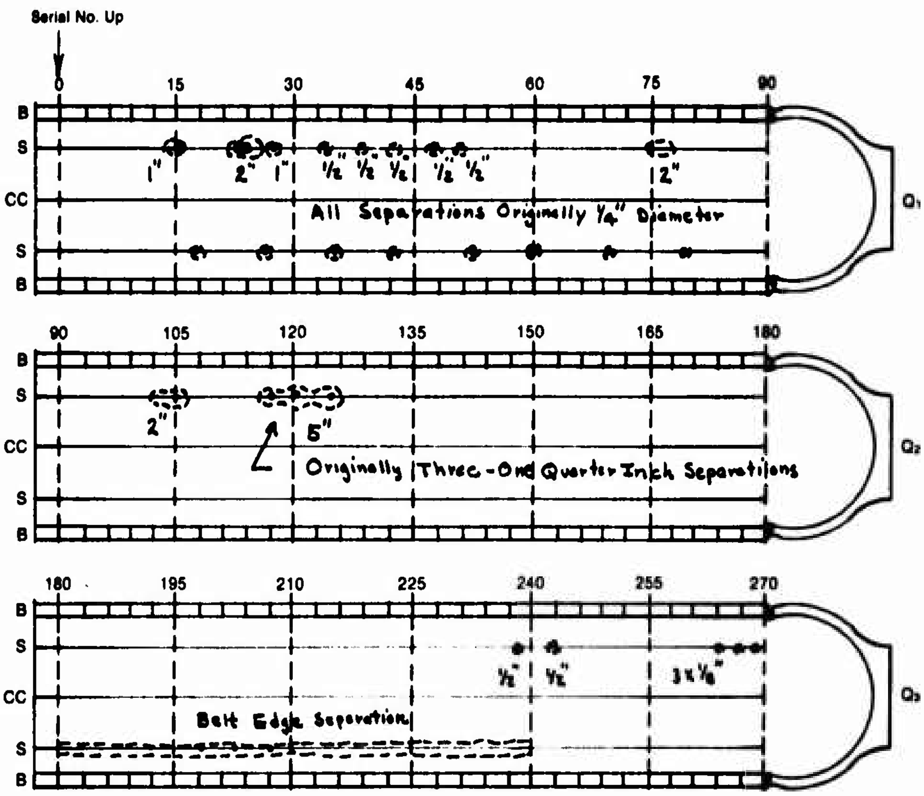


FIGURE 23
CHART OF SEPARATIONS IN TIRE EXAMPLE IX

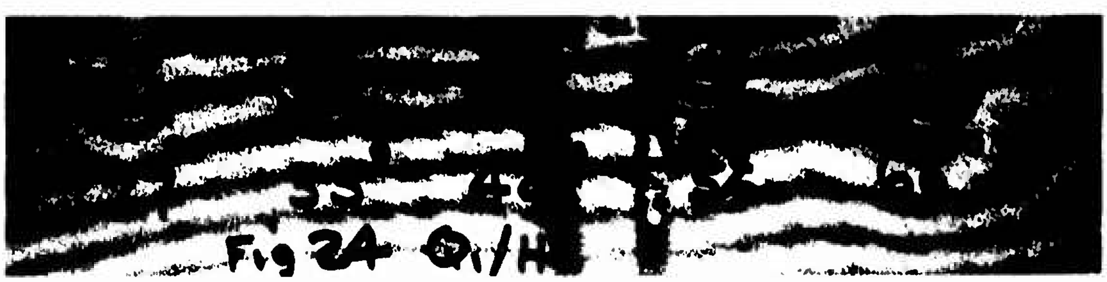


FIGURE 24
TIRE EXAMPLE NO. IX – Q_1/H_1

EXAMPLE NO. X

The following example, a 10.00R22, has a high probability of failure prior to run out, despite the fact that the original carcass contained a single separation at 255°. The original hologram revealed a very strong, highly uniform tire. The area around the original defect, see Figure 25 and Figure 26, possessed a high degree of structural integrity. However, after 40,800 road miles, the 225° region is considerably weakened from bead to bead. Four additional separations have appeared: ¼ inch at 250°, ¼ inch at 255°, ½ inch at 257° and ½ inch at 260°. In addition, the original elliptically shaped separation with a minor axis of 0.9 inch and a major axis of 1.4 inches has propagated to an ellipse where the minor axis is now 1.3 inches wide and the major axis is 2.6 inches wide. The ratio of the H_1/H_0 ply to ply separation height is three times as large at the same test vacuum level. This tire has a high probability of failure prior to 60,000 ± 10,000 miles. Under any form of under-inflation and/or overloading condition, it would probably fail, if run on a continuous basis, within a few hundred miles.

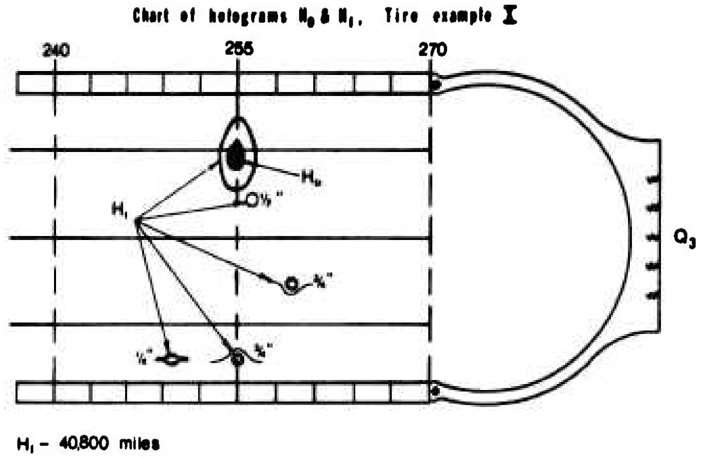


FIGURE 25
CHART OF HOLOGRAMS H_0 & H_1, TIRE EXAMPLE X

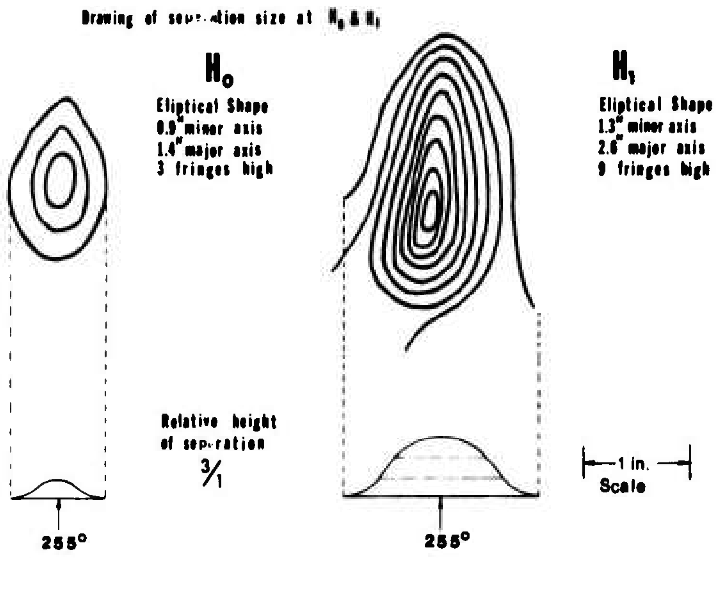


FIGURE 26
DRAWING OF SEPARATION SIZE AT H_0 & H_1

EXAMPLE NO. XI

The following tire, a 10.00R20, contained a 7-inch long separation at the upper belt edge, as exhibited in Figures 27 and 28. The tire failed and was removed from an indoor low speed test wheel at 1078 miles. The probability of such an early failure was extremely high since the belt edge was originally open to the extent of over 10 square inches. A photograph of the failed tire, which was cut at 79°, is shown in Figure 29. Figure 30 is a photograph of hologram H_1 at 1078 miles over the failed region extending from 64° to 145°. Such a tire requires little discussion.

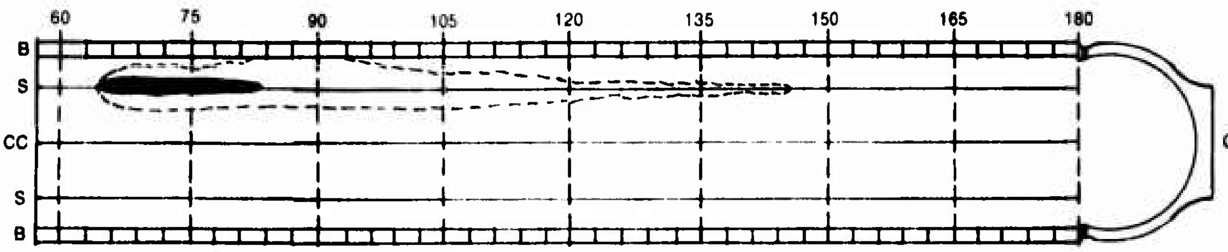


FIGURE 27
CHART OF SEPARATIONS IN TIRE EXAMPLE XI

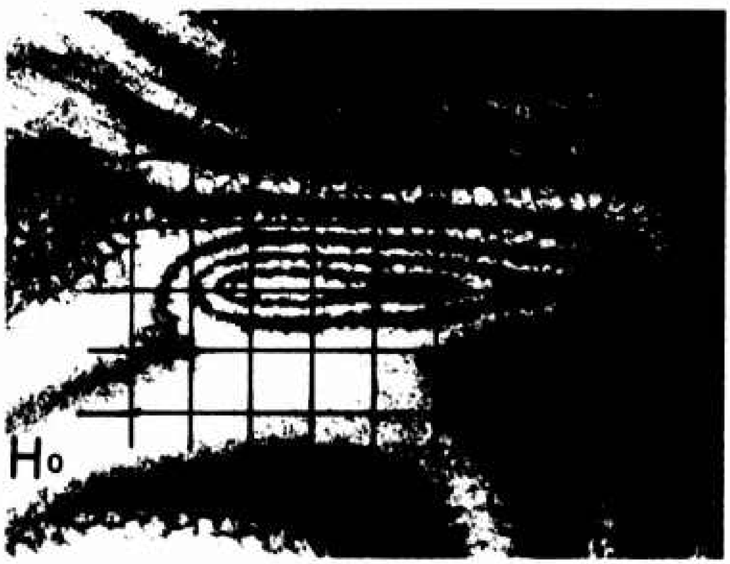


FIGURE 28
ENLARGED PHOTOGRAPH OF HOLOGRAM, H_0, OF ORIGINAL SEPARATION – GRID LINES ARE 1" APART

FIGURE 29
PHOTOGRAPH OF FAILED TIRE, CUT AT 107°, AFTER FAILURE AT 1078 MILES

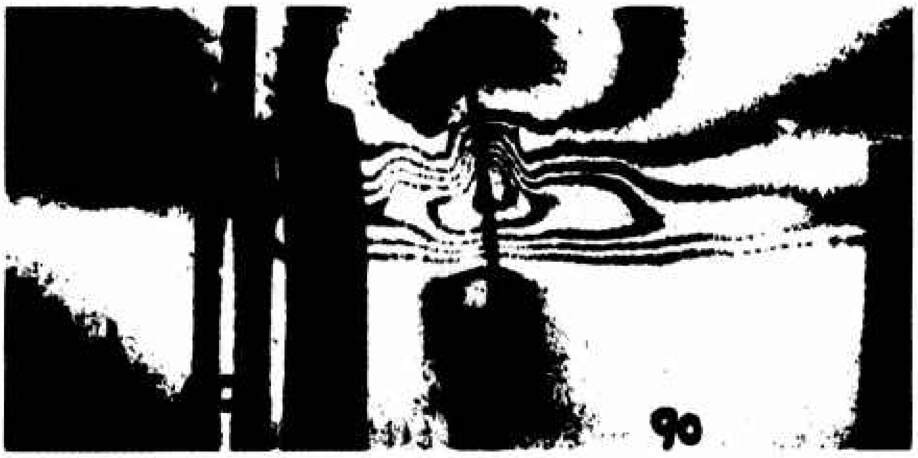


FIGURE 30A

FIGURE 30B

EXAMPLE NO. XII

Our final example, a 11.00R22.5, also failed on a low speed indoor test wheel at 5280 miles, due to belt edge separations. The original hologram exhibited approximately fifty separations, as shown in Figure 31A and Figure 31B. Most of the separations were small with the exception of about a dozen, which were about 1 inch in diameter, as exhibited in Figure 31. As you will note in the chart, the separations are spread throughout most of the carcass. The larger 1 inch diameter separations were rather evenly distributed with one and two inch spaces between them. It is interesting to note that the spaces between the defects were strongtly bonded, which would suggest that it might take the first portion of the tire's life to break down these gate barriers. The tire failed massively in the vicinity of 210°, however, extensive separation existed in addition outside of the immediately failed region. It was quite evident in H_0 that this tire would experience an early failure. It is rather surprising that it lasted up to at least half of its expected drum life. We note, however, that the multiple-circular type separations along the belt edge with the gate barriers mentioned above and noted in Figure 31, do not lead to failure as quickly as the completely open edge observed at H_0 in example IX. When the belt edge is completely open over an inch wide and extends for a few inches the failure appears to take place very quickly. In case of multiple-circular separations in the ½ inch to 1 inch diameter category where reasonably good adhesion exists between separations, it appears to take a little longer to reach failure since more mileage is required to open up the extended edge.

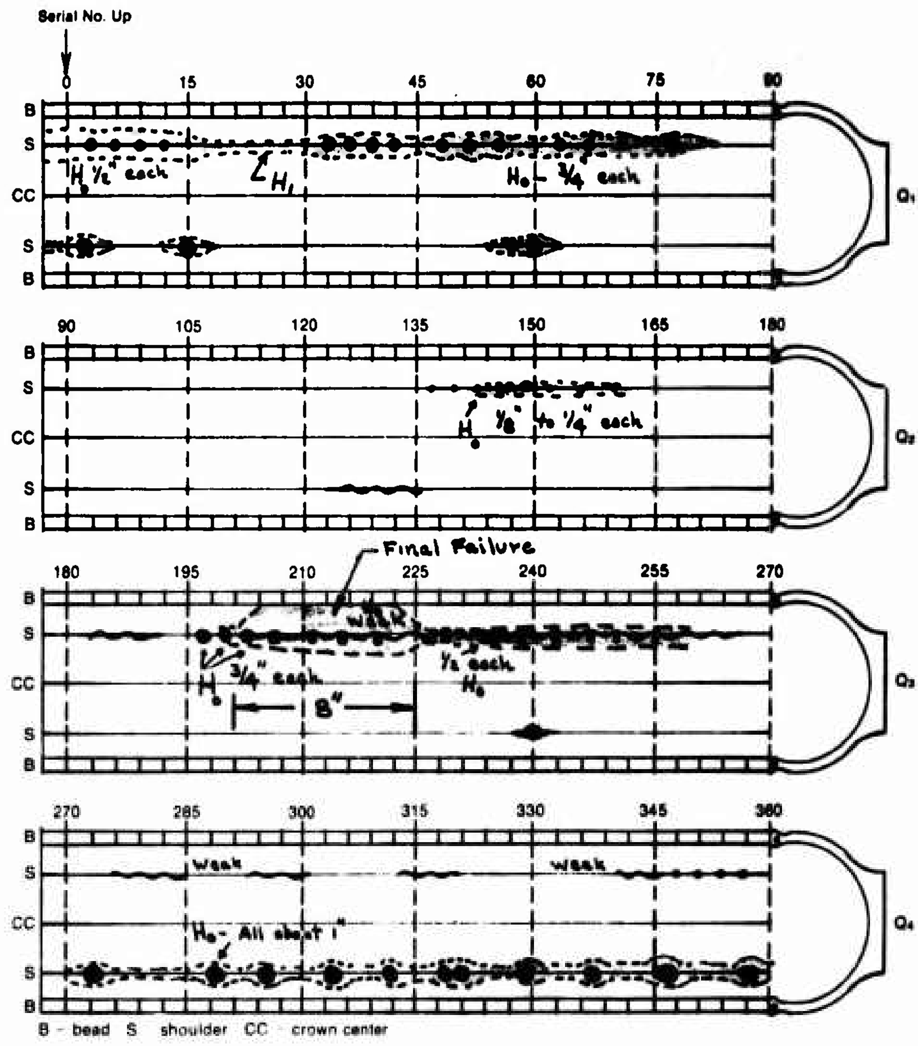


FIGURE 31A
CHART OF H_0 AND H_1 FOR EXAMPLE XII WITH ORIGINAL SEPARATION IN BLACK AND FINAL SEPARATION IN GRAY WITH DASHED OUTLINE

FIGURE 31B
PHOTOGRAPH OF HOLOGRAM, H_0, TIRE EXAMPLE XII BETWEEN 290° AND 350°

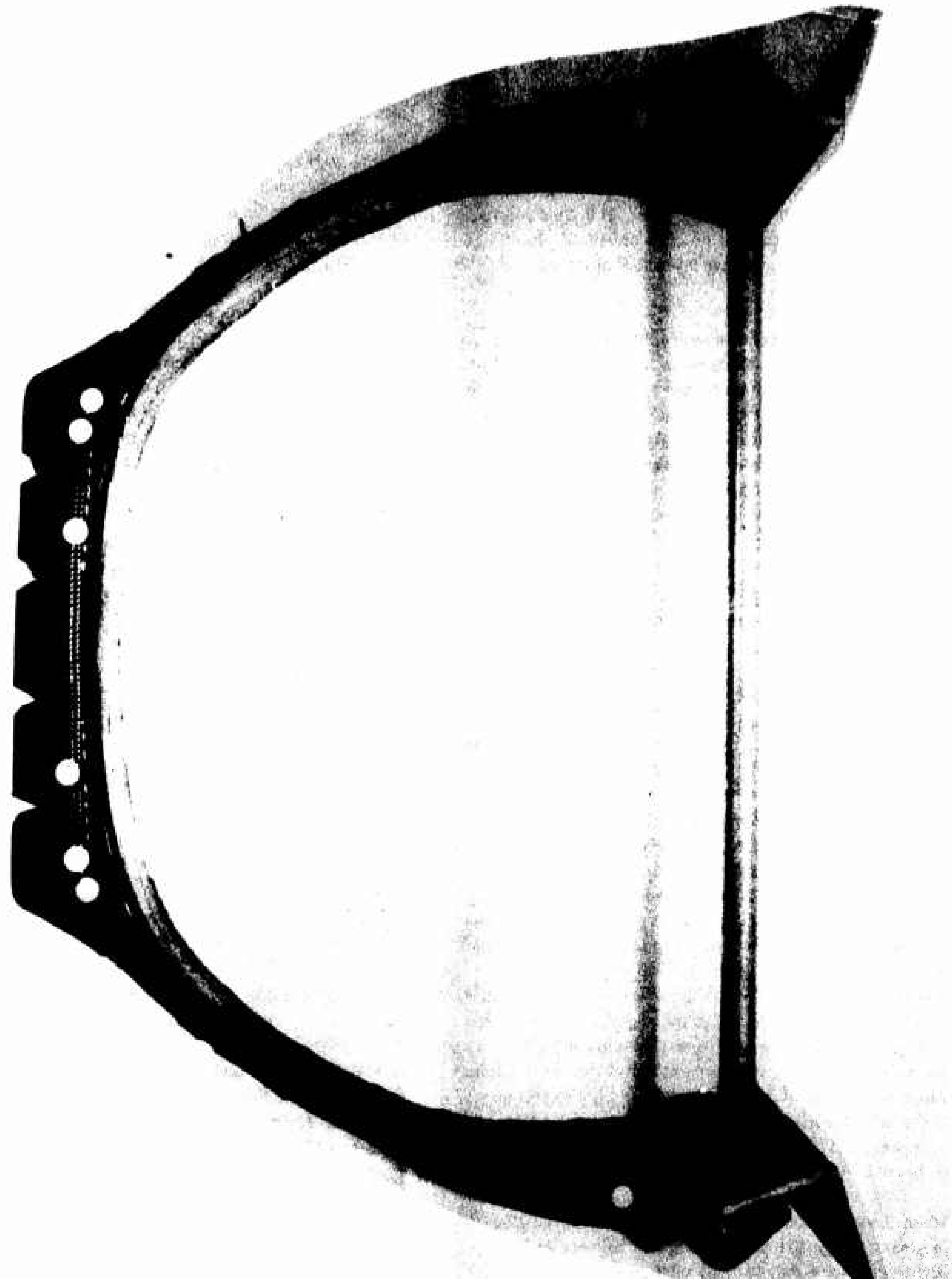


FIGURE 32
REGIONS WHERE (WHITE DOTS) SEPARATIONS MOST TYPICALLY APPEAR IN RADIAL TRUCK TIRES

CONCLUSIONS AND SUMMARY

In this paper a brief review has been given of recent methods employed in holographic nondestructive testing of radial truck tires. Through the presentation of a dozen representative examples, which were selected from hundreds of tires, an affirmative answer can be given to the prime question: Do inner ply separations propagate as a function of mileage in radial truck tires? The same conclusion was drawn in each of the cases presented. In hundreds of examples, we have invariably observed propagation.

Physical cutting of tires has always confirmed our separation location accuracy. The final accuracy of positions and size of defect has been more a matter of accurately marking a grid in the tire, rather than the test method itself, which provides more than sufficient accuracy for propagation studies. Comments on rate of propagation have been made in the examples given, however, the general study of rate is a highly complex one and will be dealt with in a paper being prepared for publication.

Based on the examples studied to date, separations in radial truck tires usually appear in the regions indicated by white dots in Figure 32.

As a generalization we would conclude that 1/8 to 1/4 inch separations will not usually lead to failure in the first 100,000 miles as long as a number of them are not clustered together. In the range of 1/4" to 1/2" they may lead to failure prior to run out, especially if a group of separations are clustered in the same general area. At the 1/4" to 1/2" size in the original tires the probability of having a sound carcass for recapping is highly questionable. With a 1/4" to 1/2" separation in H_O the probability of failure in the first 50,000 miles is very low. Most separation occurs along the stabilizer ply edges as opposed to crown locations, which propagate more slowly. In the 1/2" to 1" category the probability of failure prior to run out becomes much higher, however clustering is again of prime concern. If the tire has 1" separations in addition to some clustering and a weak carcass originally (low structural integrity) the tire will have a high probability of failure before its mid life expectancy. If the belt edge has a few 1" separations and the carcass possesses good structural integrity otherwise, the tire may go beyond the 50,000 mile point.

When the separations are above 1" especially in the 2" or 3" or greater category, the tire system will fail very early. If the belt edge is only partially open, it may take up to 20% or 30% of the expected life. However if the separation is completely open, failure will usually occur before 20% of the life expectancy and sometimes within 10%. No clustering is necessary when the opening is greater than 2 or 3 inches.

Three one inchers separated by bonded gate regions will act similar to an open 3 incher only after the prerequisite 20,000 or 30,000 miles is run to break down the gate spaces between the original separations. Failure will then proceed over the next 10 or 20% of life expectancy just as in the case where the 3" opening failed in the first 10% or 20%.

In many cases propagation, holding all other parameters constant, proceeds in direct proportion to mileage. Sudden changes in propagation rate have seldom been observed to date with the obvious exception of the final failure stage. The progression of propagation is surprisingly well behaved and non erratic. With further study rather accurate failure probability statistics would appear to be within reach.

To place the above comments in proper perspective, we need to ask what about the hundreds of control tires which ran beside the ones discussed earlier. A tire, which possesses a high degree of structural integrity, absence of separations, etc. in addition to good holographic uniformity, invariably performs extremely well. Such a tire has a very low probability of failure with the obvious exception of road hazard failures.

Moreover we have observed that tires which exhibit a high degree of fringe uniformity in H_O, such as the example shown in Figure 33, tend to deliver run out mileages well above

FIGURE 33
PHOTOGRAPH OF A HOLOGRAM (BEAD TO SHOULDER — TOP TO BOTTOM OF PHOTOGRAPH

the average tire in a given tire group. Tires, which exhibit a low degree of fringe uniformity, deliver on the average lower mileages in addition to having a slightly higher probability of failure (note Figure 34).

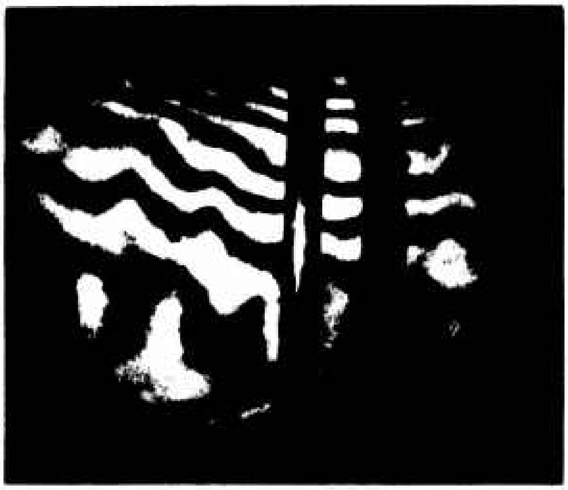


FIGURE 34
PHOTOGRAPH OF A HOLOGRAM
(BEAD TO BEAD)

Further comments on holographic uniformity are not in order here. However they have been briefly touched upon to enable us to make the following statement, which is needed to further establish a proper perspective. Separation will typically propagate at a higher rate in a tire which possesses poor overall fringe uniformity as opposed to one with good fringe uniformity. In other words a tire containing a separation which runs down the road with a minimum amount of scrubbing action, similar to the manner in which a true steel ring or barrel would roll, experiences a slower rate of separation propagation. Hence a consideration of the overall propagation of separations should take the tire's overall fringe uniformity into account.

In conclusion inner ply separations in radial truck tires do propagate and do significantly increase the probability of premature failure, if they are of sufficient size in the original carcass.

ACKNOWLEDGEMENT

The author wishes to gratefully acknowledge the assistance of the Firestone Tire and Rubber Company. Small portions of the data were obtained from previous tire studies [1]. However, a major portion of the work reported in this paper was financially supported by the Firestone Tire and Rubber Company.

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1. Grant, R.M., "Evaluation of the Structural Integrity of Pneumatic Tires by Holographic Interferometry", *Proceeding of the 1973 Symposium on Nondestructive Testing of Tires,* Edited by Paul E. J. Vogel, Materials Manufacturing and Testing Technology Division, Army Materials and Mechanics Research Center, Watertown, Mass., held at the Parker House, Boston, Mass., 10-12 April 1973, pages 33-46.

2. Grant, R.M., and Brown, G.M., "Holographic Nondestructive Testing", *Materials Evaluation,* April 1969.

HOLOGRAPHY AS APPLIED TO AIRCRAFT TIRES

W. C. Shaver, Vice-President – Engineering
Air Treads, Inc.
Forest Park, Georgia

To those of you here who have not heard of Air Treads, let me say that our firm is one of the largest rebuilders of air-c[illegible] the world. We operate six facilities strategically located throughout the United States where we rebuild aircraft tires for all of the Nation's airlines except two small ones. We do aircraft wheel and brake overhaul for the airlines. We are also the largest rebuilder of aircraft tires for the United States Navy and Air Force.

We have built our business by specializing on aircraft tires exclusively. In so doing, we have been able to concentrate our efforts in this one field and have been able to incorporate the latest machinery and techniques for aircraft tires.

Air Treads has closely watched the developments made in the NDI field. We did some experimenting with Infrared equipment, we did a good bit more experimenting with Thru-Transmission Ultrasonics but, much more extensively, our NDI work has been with Holography.

We have been intrigued and fascinated by it from the very first day and we never ceased to be amazed at its unbelievable accuracy in detecting flaws in tires. Paul Vogel asked me to appear on this program to give you some of our results in inspecting over 8,500 aircraft tires by Holography. Maybe some of our results and findings will help this group evaluate the true worth of nondestructive inspection by Holography.

We installed a G.C.O. Laser Holographic Tire Analyzer in the summer of 1971. We put this machine in for our own research and development studies in commercial aircraft tires. We did it on our own initiative because, at that time, there was no requirement for NDI in military tires.

In order to gain experience in the use of the machine and in the interpretation of the Holograms, the first months were spent in making Holograms of tires from our scrap pile.

Those in which we found anomolies, we would mark and saw up and locate the anomoly. We have sectioned a few hundred tires and in very, very few cases were we unable to find the flaw that the film showed.

After we were fully convinced that the machine told us the truth and we had learned something relating to the size of the anomoly, we decided to go into the study of tires being used daily on one of the commercial airlines. We selected one of our customers where the volume of tires was such that we felt we could handle them one hundred percent across our Holography machine. These were DC-9 jet main-wheel tires. This study began in February, 1972 and continued through April, 1973. The number of different tires tested amounted to 762 but these 762 tires were Hologrammed and checked at each retread level until such time as they had been scrapped out. It so happens that the highest retread level and consequently, the highest number of Holograms that were taken of a single tire was at the seventh retread. Since we did each tire at each retread level, we actually tested the tires 1634 times – there were 1634 Holograms made and studied. Thirty of these 1634 were found to have separations in them. This works out to be 1.8%. The first half dozen were sectioned by us so that we could study what the separation looked like. It so happened that all of these 30 separations were not in the shoulder area of the tire but were under the thread area which our experience has shown us to be the least troublesome. The remaining two dozen tires with the small separations in the thread area were allowed to go into service. All of the Holograms were filed by serial number and by retread level. When we would get the tire back for the next highest retread level, the latest Hologram at the current retread level was compared on a side-by-side basis with all previous retread level Holograms done on this same tire. The main thing that we were looking for was to see if there was an alarming rate of growth in the size of the separation. Not one of these tires had to be scrapped because of the fact that the separation grew excessively large. All of the 762 tires that started this program were eventually scrapped, at various retread levels, because of normal aircraft tire reasons. The two reasons that are the cause for the largest number of scraps are cut beyond limits and brakeheat damage. During this fourteen month period, the only two tire problems that this airline had consisted of one blow-out and one tire that was run under-inflated and ruined.

In the latter part of 1972, the Navy added an NDI requirement to their contracts for high speed aircraft tires. This requirement, basically, was that all of these tires had to be nondestructively inspected by an acceptable NDI process and that we be able to identify any unbond or separation one-half inch in diameter or larger in the shoulder to shoulder area. Any separations of this size were to be rejected.

From November, 1972, through Septemer 17, 1974, we have examined 6,578 Navy tires. Sixty-eight were scrapped because they had separations one-half inch or larger and did not meet the requirements of the specification. This is 1.0% – slightly less than the 1.8% we found on the commercial airline tires. In addition to these 68 that were scrapped, 140 other Holograms showed very small anomolies that were smaller than the one-half inch acceptance limit. All of these 140 tires were shipped along with the other 6500 or so that had no anomoly. None of these 140 tires caused any problem of any kind to anyone's knowledge. Would the 68 tires that were scrapped have caused any problem? No one really knows. Some might have if the separation was in the shoulder area and quite large. If the separation was in the tread area and not extremely large, they probably would not have caused a problem. We know that we had 24 instances of this type of separation in the commercial airline tires that didn't cause any problem even through the seventh retread.

In these days of inflation where our costs spiral upward faster than we can print price lists, it is a never ending search for ways to reduce the cost of our product. So far, we have had to charge all of our nondestructive inspection off to research and development costs. We figure that it costs us around $10.00 a tire to make a Holographic inspection. No airline would permit this kind of a price increase just to get a nondestructive inspection. Just over two years ago, when we were experimenting with ultrasonics, the representative of the equipment manufacturer went to quite a few of the major carriers to ask if they would consider sharing in the development costs of a production machine or would pay $.50 tire to have their tires non-destructively inspected. Their answer in both instances was no.

It is our belief that the true value of NDI will never be established until we learn just what kind of separation and where it is located will lead to a tire failure. We believe that there is no concept more reliable or accurate than Holography. Air Treads is more concerned that the wagon doesn't get ahead of the horse. We hope that people who have control of tire specifications, whether in the military or commercial industry, do not build up such a hunger for the nondestructive testing of their tires that the specification requirements get far ahead of what is commercially available to the tire rebuilders such as Air Treads in the way of machinery to do the job. We have a superb machine but it is so slow and expensive that we cannot use it for all of our tires. We process over 140,000 tires a year in five plants. We hope to see the day come when nondestructive inspection machinery will be inexpensive enough and fast enough whereby we can have five machines doing 100% of our tires. Such machinery is not available and ready for purchase today for use in production line testing.

Finally, I was going to show you some slides of our nondestructive testing equipment, but this was all shown on the fine movie on "Navy Tire Rebuilding" that Gwynn McConnell just ran.

QUESTIONS AND ANSWERS

Q: Why do you adamantly tell me that you would not send a tire to be dynamometer tested without it being inspected or nondestructively inspected first; and yet you're willing to risk 150-200 lives on an aircraft because they can't afford 50¢ a tire plus the loss of a $15M aircraft?

A: In the first place, I said what some aircarriers said about 3 years ago and the aircarriers were having an extremely hard time. The picture's changed somewhat but it's not all good. They still must watch every penny. The second point I wanted to bring out, that may not be their opinion today. The second point is that to our knowledge, and we've been in this game for years, there has never been a human life lost in an aircraft accident because of an aircraft tire failure. We don't know of it if there is and so it's very easy to say "but what about the value of those lives of those 150 people that you are endangering?" No, that's not fair. In the realm of possibility, I guess sure, anything is. But you could throw the tread off of the tire and the tires will still run on the bald surface. But it's not so dangerous. I hope to see the day come when nondestructive inspection of some type will be so available at a price and fast enough where we can do every tire we process that way, but right today at least we have to have a machine that is capable of running around 250 tires a day and we don't believe there is anything we can have today that can do 250 tires a day. I hope that next week, next month, next year, it will be there. Whenever it comes along you'd better believe we will have it. But it's from a standpoint of a quantity of time doing 250 tires a day is no easy job. After all we have learned and someone else brought it out today, the analysis, the observation, the entire process is a detour from normal and is so fast that you don't even have time to make a good analysis of it. That's cutting corners and you could miss some flaws.

Q: Well, I take it that I inferred from your presentation you were not in favor of nondestructive inspection and I take it that I was totally mistaken, that you are highly in favor of it, if somebody paid for it. Is that correct?

A: Yes and the fact that we would not gamble on quite a few thousand dollars on a dynamometer test without first

having evidence that says it's sound as a dollar should suggest that yes we do believe in nondestructive inspection very much.

Q: You indicate that your plant produces possibly 150,000 retreads a year, can you tell me what your reject rate comes to?

A: I don't have the information with me. Everytime we run, the info is taken from process cards and keypunched for computerization. We do have the computer reports that its all printed on, it tells you what percent by about 16 different reject regions, cost that a tire, what % they drop out, etc.

CHAPTER V – INFRARED TIRE TESTING

INFRARED SESSION
INTRODUCTORY REMARKS

Mrs. Dianne Earing
Vice President for Marketing
Sensors, Inc., Ann Arbor, Michigan

Infrared is one of many techniques in use for NDT of tires. Perhaps its most unique advantage over other test methods is its ability to observe tires under dynamic test conditions. Under these conditions, the tire can be observed in a situation which closely simulates the actual operational conditions of a tire, i.e., rotating and under load. Under these conditions, tire flaws such as broken cords, ply separation and fabric delaminations produce localized temperature anomalies which can be observed with infrared instrumentation.

Several manufacturers have developed instrumentation dedicated to infrared testing of the rotating tire. In general two types of systems are available:

1. The imaging system which produces a thermal map or picture of the tires, either by optical or mechanical scanning; and

2. The point radiometer which observes a circumferential swath of the tire as it rotates. The audience is referred to the following publications for a more complete survey of the instrumentation available for infrared tire testing:

   a. *Proceedings of the 1973 Symposium on Nondestructive Testing of Tires,* held 10-12 April 1973, Parker House, Boston, Mass. Sponsored by the Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172. Edited by Paul E.J. Vogel. Distributed by NTIS, Springfield, VA., NTIAC 74-1.

   b. S. Bobo, "Recent Developments in Use of Infrared for Nondestructive Tire Testing", *Materials Evaluation,* July 1974, pp. 147-152.

   c. P.E.J. Vogel, *The State of the Art of Nondestructive Testing of Tires.* Army Materials and Mechanics Research Center, Watertown, Mass. 02172. October 1973. AMMRC PTR 73-9.

Also, our next speaker, Mr. Pica from Monsanto, will discuss a computerized infrared system which utilizes a sophisticated software package to analyze the infrared data as an aid in determining the signatures of actual defects in tires.

To date most of the data presented in the literature or at previous symposiums have been laboratory measurements. These are conducted using a test wheel with the ability to run the tire under varying load and speed conditions. While the primary use of the test wheel is for compliance and endurance testing, it provides an excellent test stand for laboratory IR measurements. However it is important that we do not lose sight of the reason and value of the lab test. Lab tests are usually done in lieu of field, or in this case, road tests for two reasons:

1. Certain variables such as environmental factors can be controlled allowing for repeatable experiments and the study of parametric effects; and

2. Lab studies in general are less costly than road tests.

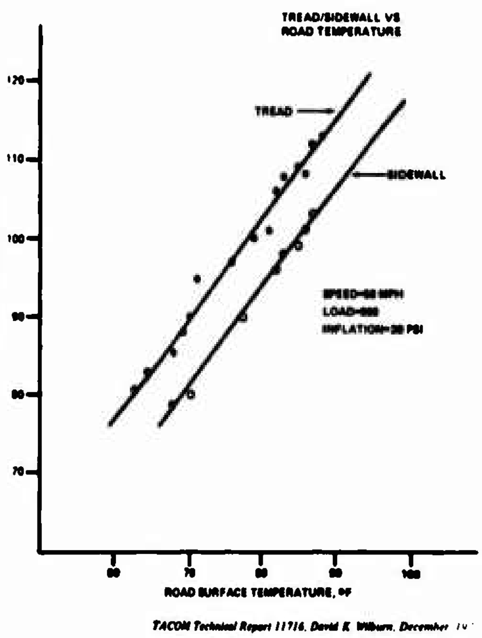
However, lab experiments are only valuable if their results can be used to predict with some degree of accuracy what can be expected during a road test. If we ignore this requirement, then the lab experiment merely becomes an academic exercise rather than an attempt to better understand the real world.

The USATAC under sponsorship from the Army Materials and Mechanic Research Center, Watertown, Mass. has completed a program to observe tires during road testing and compare the results with lab tests. This study was conducted by Dave Wilburn and the results have been published in a TACOM technical report.

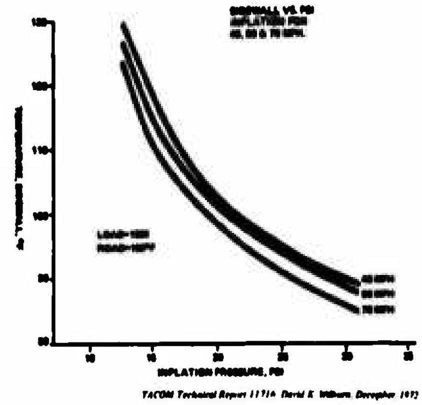
The TACOM study was based on approximately 5000 miles of highway testing performed on ten tires – some with induced defects. The test vehicle was a commercial passenger car instrumented to record environmental parame-

ters such as road temperature, air temperature and solar load. IR instrumentation manufactured by Barnes and Sensors was used to measure the average tire temperature and temperature differences of the test tires under varying loads, speeds and inflation pressures. The results of this program indicate:

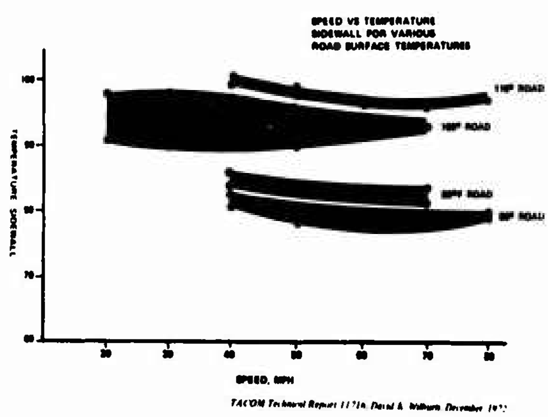
1. Road surface temperature, air temperature and solar heating of the tire influence tire operating temperatures more than speed or load. (Slide 1)



SLIDE 1



SLIDE 2



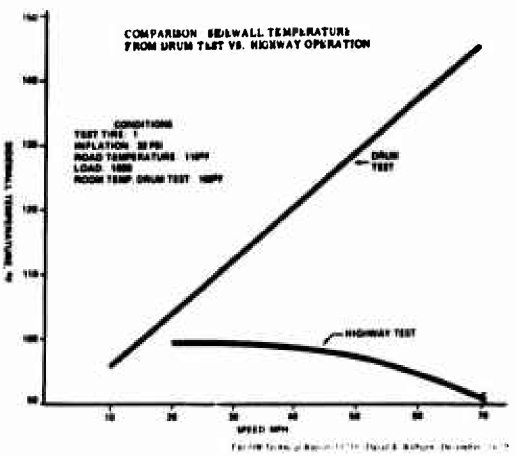
SLIDE 3

2. The most important operational factor affecting tire temperature is inflation pressure. Load and speed have a much lesser affect on tire temperature. (Slide 2 and Slide 3)

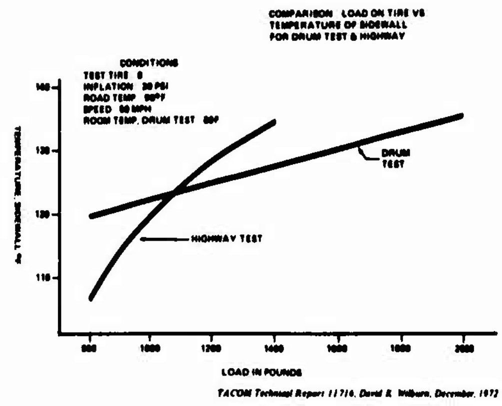
3. In direct contrast to its effect during a road test, speed is proportional to operating temperature in lab tests because of the lack of convective cooling. (Slide 4 and Slide 5)

4. Temperature anomalies associated with defects can be observed in road tests as well as lab tests. (Slide 6)

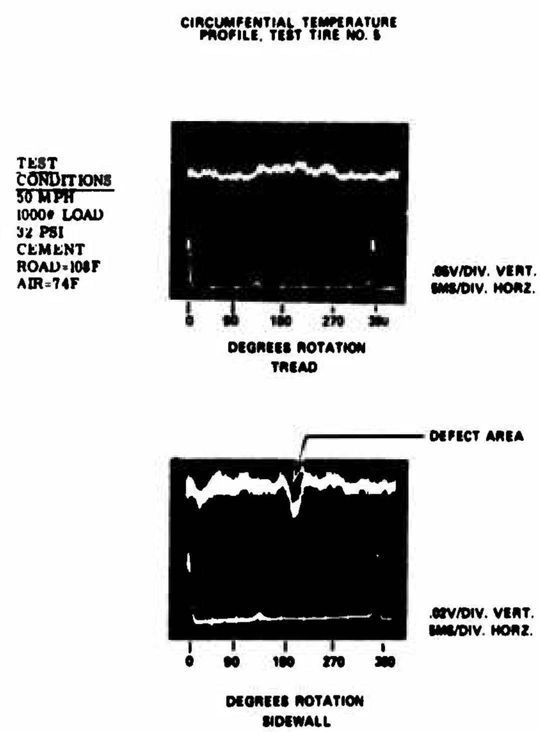
This study is another piece of evidence which supports the use of infrared as an NDT tool and provides some valuable data to bridge the gap between lab and road tests. Our next speaker, Mr. Pica, will describe a further advancement in infrared testing. The system developed at Monsanto provides the capability for quantitatively analyzing the thermal characteristics of a tire as a function of time. Its ability to handle a large volume of data on a statistical basis is an important contribution to NDT in general as a methodology for determination of unique signatures which can be correlated with physical defects.



SLIDE 4



SLIDE 5



TACOM Technical Report 11716, David K. Wilburn, December, 1972

SLIDE 6

MONSANTO TIRE FLAW DETECTOR NON-DESTRUCTIVE INFRARED TIRE TESTING

Dominick Pica
Manager, New Products and Growth
Monsanto Company

A non-destructive test method for detecting flaws in tires which has been of interest to the tire industry is the measurement and interpretation of thermal changes on the surface of a tire rotating under load on a test wheel. The heat generated in a dynamically stressed tire is observed by infrared techniques. Thermal radiation is sensed through the use of an infrared detector, or radiometer, which is focused on a portion of the tire surface area. Signals are generated by the radiometer which are proportional to temperature variation over the tire surface. These signals are fed to a visual display system, such as a cathode ray tube, and observed by an operator to detect any significant changes in the data which might indicate flaws or areas of structural weakness in the tire.

Unfortunately, this method for detecting tire flaws depends upon the memory and eye of an observer to identify and interpret significant changes among the characteristic peaks and valleys of normal infrared emissions. This has proven difficult and often undependable in practice. The time varying signals from the radiometer are composed of true signals and noise signals and the noise component frequently causes confusion in interpreting the visual readout. Also, the brand name, size, serial number and other identification indices on the tire surface cause extraneous variations in infrared emission which must be distinguished from changes associated with flaw development. By the time a flaw is positively detected, it has often progressed to the point where the tire is destroyed before the test wheel can be stopped and as a result the location and nature of the defect cannot be determined.

Monsanto has developed a new non-destructive tire testing instrument which represents a significant advancement in infrared testing from both engineering design and operating standpoints. This testing instrument, known as the Monsanto Tire Flaw Detector (TFD), provides a completely new computer controlled technique for interpretation and presentation of the test results which greatly improves the effectiveness and utility of IR tire testing.

The principal features of the TFD are:

- Detection and location of failure points
- Automatic operation
- Termination of the test prior to destructive tire failure
- Computer controlled system for data acquisition, processing and interpretation, and presentation
- Visual data display with continuous recording if desired
- Printout of critical data values

The TFD differs from all previously available IR systems in that test results are not presented solely in terms of surface temperature of the tire. By appropriate computer processing, data readouts are displayed as a straight line. Areas of localized temperature change indicative of flaw development are shown as readily observable deviations from this straight line with the magnitude of the deviation proportional to the degree of temperature change. This computer technique significantly improves sensitivity and reduces the noise component of the radiometer signal. Limits can be set for temperature changes and when these are exceeded a warning system comes into operation and the test can be automatically terminated before destruction of the tire occurs. A printout shows the precise location of the flaw. These features allow a high degree of automatic operation with reduced operator variables and attention.

The principal components of the TFD are the radiometers, the scanning mechanism, and the computer controlled data system.

Figure 1 is a photograph of the TFD operating in conjunction with a standard test wheel and illustrates the relationship of the radiometers and scanning mechanism to the tire and

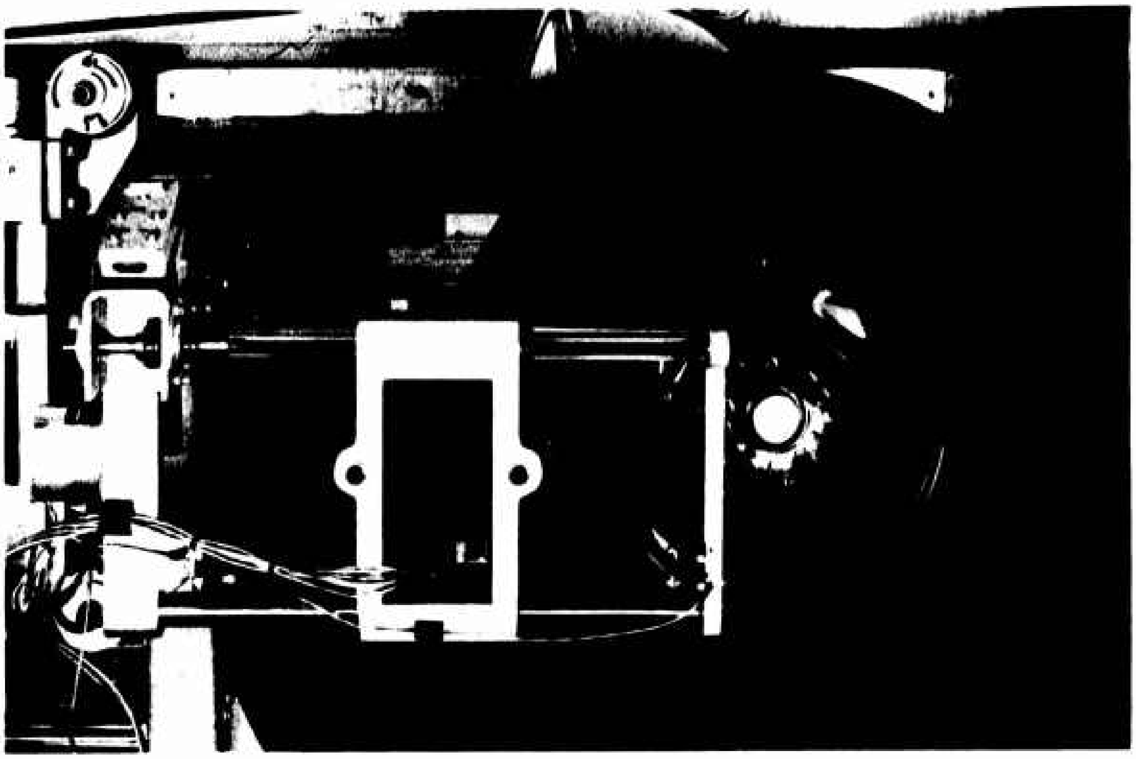


FIGURE 1

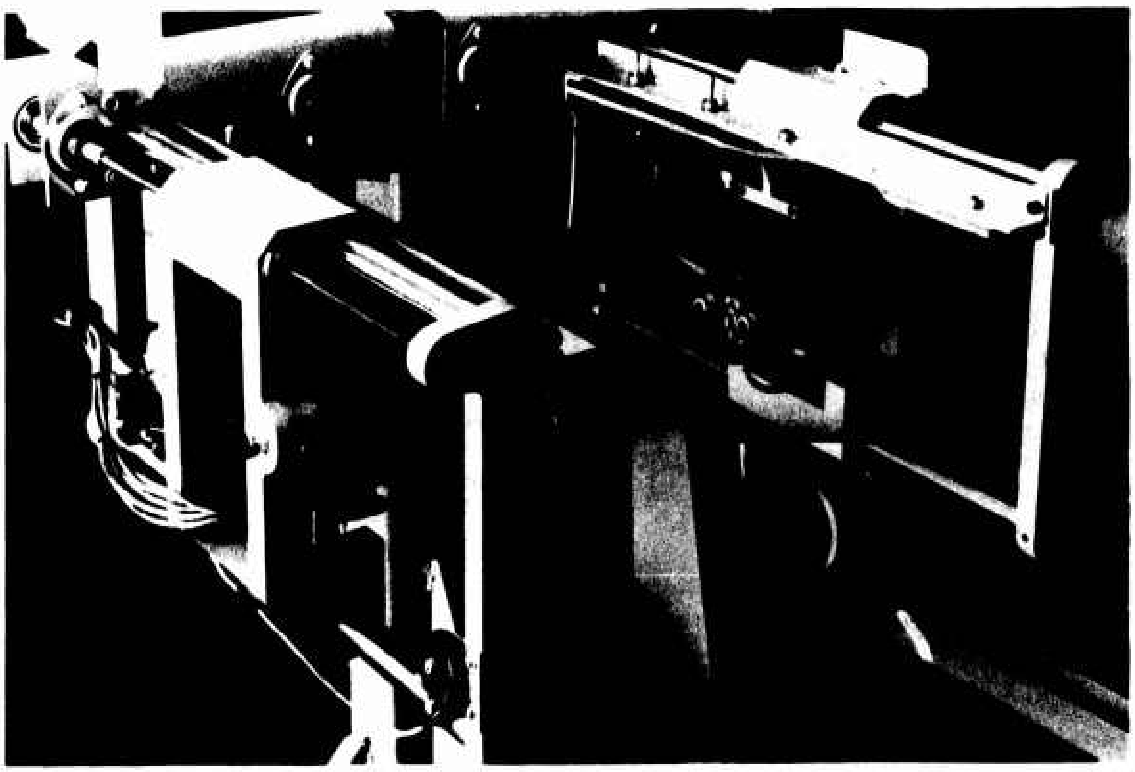


FIGURE 2

test wheel. One radiometer is mounted in front of the test tire and a second radiometer, not visible in this photograph, is mounted at the rear of the tire. These radiometers move along the scanning mechanism assembly scanning the tire from rim to tread on both sides. The complete tire is scanned in approximately one minute.

Figure 2 is a photograph showing the scanning carriage moved away from the test wheel for clearer viewing. A stepping motor drives the threaded rods shown on both sides of the scanning mechanism which in turn move the radiometers back and forth across the tire surface. The radiometers are spring loaded in the carriage assembly housing and follow the tire contour via a cam arrangement to maintain optimum resolution. The outer edge of the wheel rim is located by a switch attached to the test wheel frame which is activated by a plate mounted on the scanning assembly. The tread position is located with an optical system mounted in the radiometers. When the radiometers view each other across the tire tread the radial tire dimension can be determined by the computer from the number of pulses required to drive the stepping motor during movement of the radiometers from rim to tread. The position of the radiometers can therefore be located relative to the fixed position of the rim edge, and changes in the rim to tread dimension due to tire growth during the test are automatically taken into account by the computer.

The radiometers used in the TFD were developed by Monsanto specifically for this application. They utilize a highly sensitive infrared detecting element with a fast response time, and feature a novel electronic cooling system which eliminates the downtime and maintenance problems associated with conventional liquid nitrogen cooling. A further improvement in the radiometers makes possible meaningful observations during tire warm-up periods. The increase in the intensity of the infrared signal per unit of temperature as temperature rises is minimized by making the output signal of the radiometer substantially independent of the magnitude of the input signal. This is accomplished without significantly diminishing the ability to sense temperature changes by application of an automatic gain control system. The radiometers have a square viewing area approximately 1/2" x 1/2", and can be operated to measure both temperature variations across the tire surface and absolute surface temperature.

Figure 3 is a photograph of the Digital PDP-12 real time computer which controls the TFD data system. Shown in this photograph are tape decks for continuous recording of test data if desired, a cathode ray tube display screen, and a teletype for printout of critical test values.

Figure 4 is a tire legend used for identification purposes. Infrared data are sampled two hundred (200) times per tire revolution and the tire is viewed as sixteen (16) radial

FIGURE 3

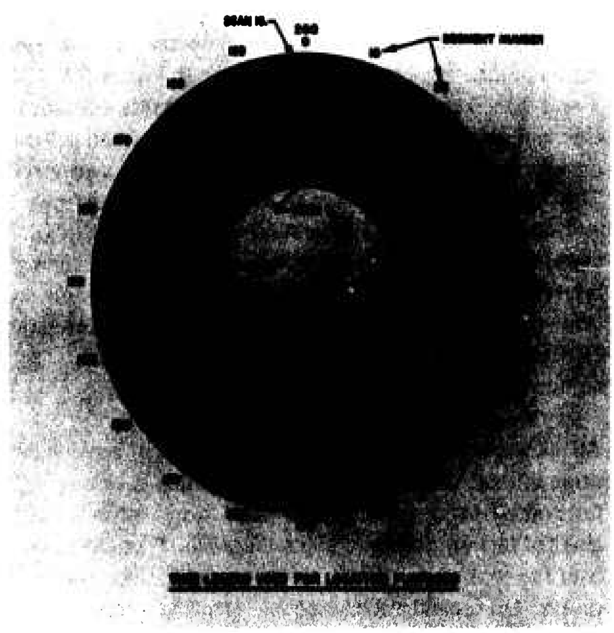


FIGURE 4
TIRE LEGEND USED FOR LOCATION PURPOSES

scan bands. The circumferential segments are determined by a proximity sensor which generates two hundred (200) pulses per revolution of the tire by sensing the leading and trailing edges of a one hundred (100) toothed gear mounted on the test wheel axle. The number and location of these segments are thus independent of tire test speed. The beginning of each revolution is determined by another proximity sensor also mounted on the wheel axle. This sensor generates a single pulse every revolution to serve as a reference point for correlating infrared data with a tire segment and for locating the segment in which a flaw appears. The radiometers move from rim to tread, sampling infrared data in each of the sixteen (16) radial scan bands. Radiometer dwell time in each scan band can be varied. Normal operation is four (4) revolutions per band. Data from each radiometer for each scan band are stored in the computer, along with identifying pulses from the proximity sensors.

The tire is then rescanned and again the data are stored in the computer. The data from the second scan are compared to data from the first scan and the differences determined. If no differences exist, a straight line will be displayed on the viewing screen. If finite differences exist, these will be displayed as deviations from the straight line in proportion to the degree of temperature change. The tire is then repeatedly scanned and the data continuously compared with a weighted average of previous scans. The differences are weighted and accumulated for increased sensitivity and signal/noise ratio thereby facilitating the detection of small temperature changes.

A more detailed description of the computer data processing technique can be made by reference to Figure 5. The signals from each radiometer, after suitable amplification and gain control, are fed to a multiplexer, and subsequently fed one at a time to an analog to digital converter. The digital signals are placed in a temporary storage area and, under control of a programmer, are processed in an adder to obtain the average values of the current scanning interval. The programmer operates in accordance with information supplied by the segment sensor, for correlation of thermal data with given segment areas of the tire circumference.

All subsequent operations are under control of a second programmer. The digital signals for the first scanning interval are temporarily retained in high speed storage and also fed to bulk storage. The average values for the scans over the first scanning interval constitute initial reference values. On second and subsequent scanning intervals these average values are again stored in high speed storage, and also continuously displayed on the cathode ray display screen as a conventional surface temperature readout. The

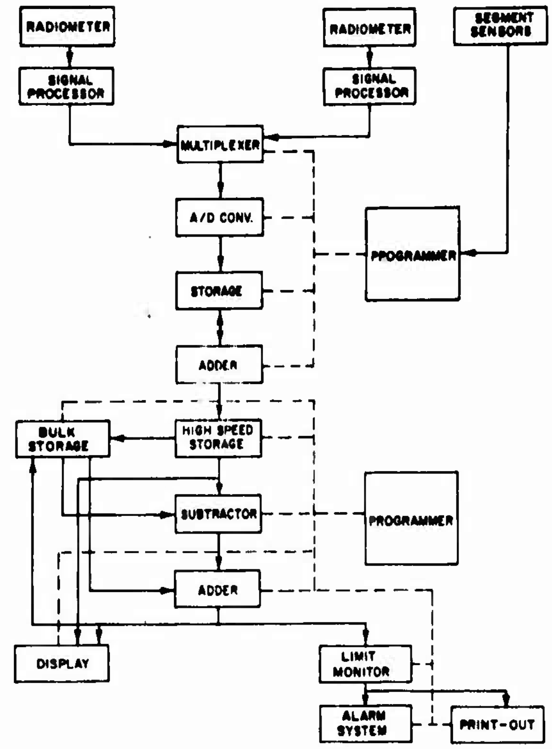


FIGURE 5

initial reference values are subtracted from the average values of the current scan and the differences are fed to an adder where they are added to the sums of previous differences. Of course, when the first differences go to the adder no previous differences will have been accumulated and the quantities added will be zero. The sums will be retained in bulk storage until the cycle is repeated and when the next differences appear in the adder they will be accumulated and the new sums will replace the prior accumulated differences in bulk storage. The accumulated difference quantities appearing at the output of the adder are indicative of the flaw development and are displayed in the cathode ray tube unit. The limit monitor is used to compare the accumulated difference curve to predetermined control limits. When a limit value is reached an alarm system is activated and it is possible to automatically terminate the test. The location of the tire flaw is recorded by a teletype printout unit.

Figures 6, 7 and 8 present application data for three (3) different tires tested on the TFD. Each figure contains four (4) photographs of the cathode ray tube display screen taken on a sequential time basis. The photographs show data associated with the front radiometer in the upper half of the picture, and rear radiometer data in the lower half. These data include the display of the current scan, and the cumulative difference curve with its upper and lower control limits.

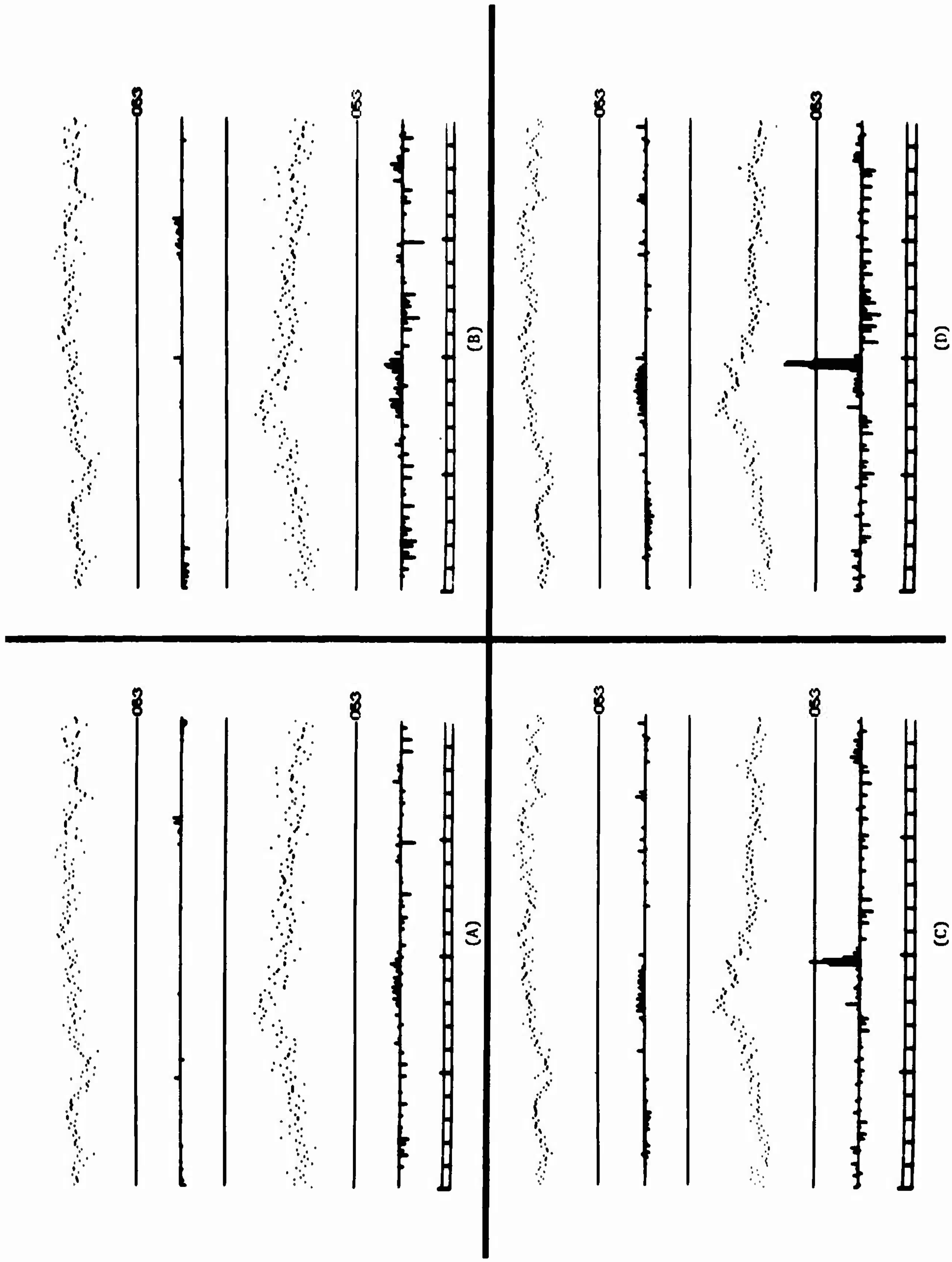


FIGURE 6

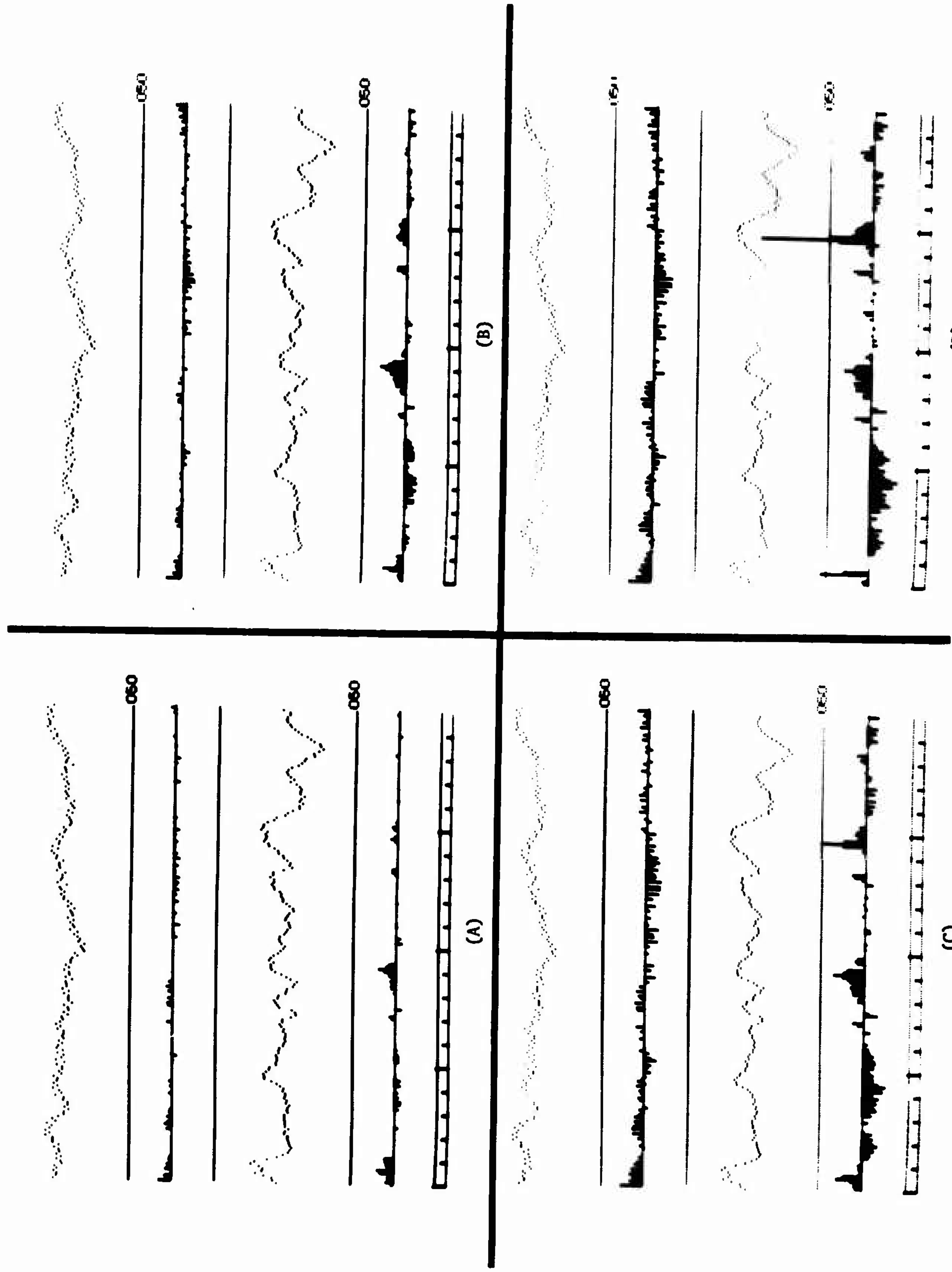


FIGURE 7

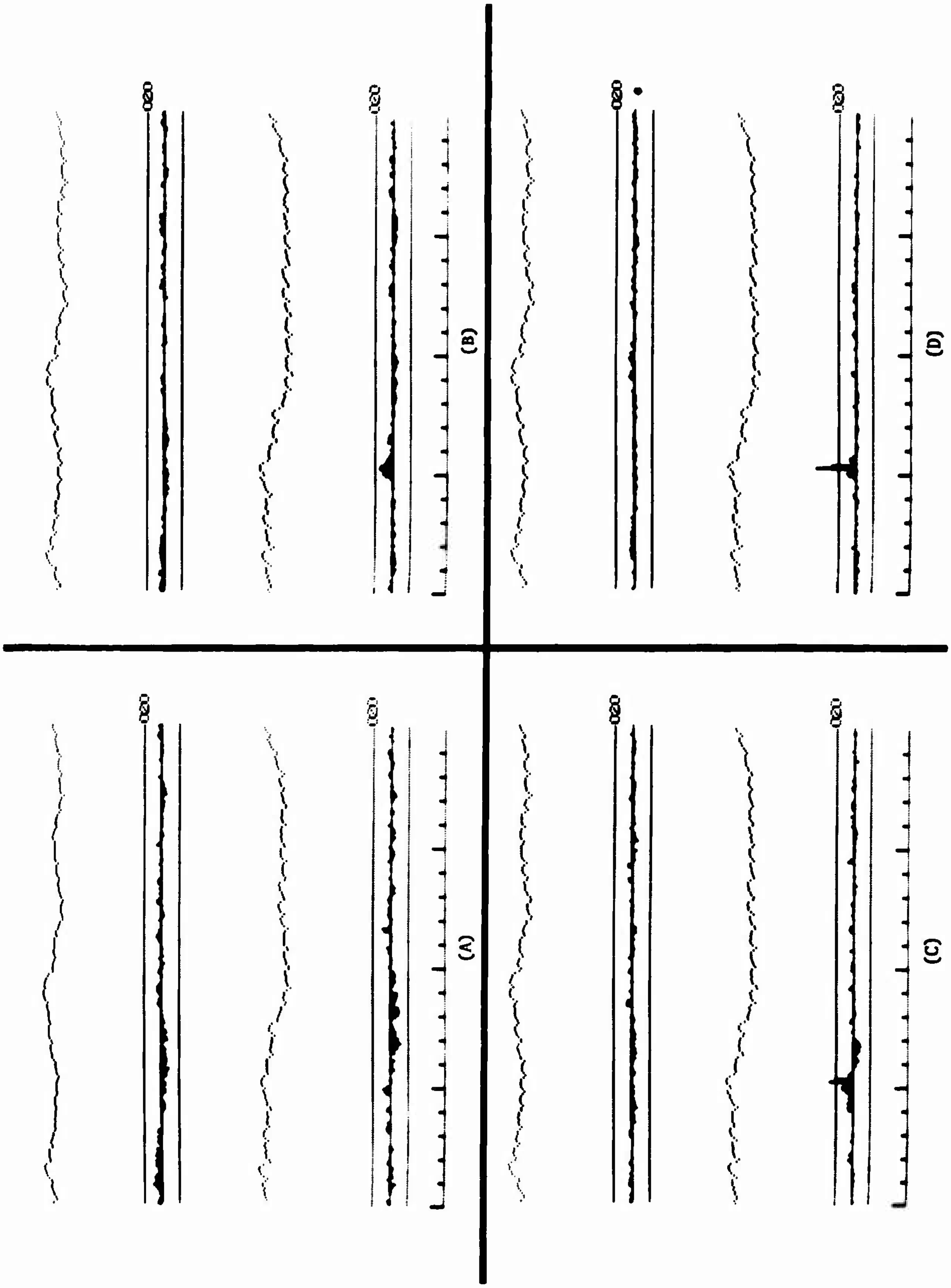


FIGURE 8

The ruled line shown at the extreme bottom of each photograph is a location index which marks the tire circumference into two hundred (200) equal segments. All three (3) tires were scanned in the shoulder area.

Figure 6 illustrates testing of an H78-15 Bias Belted (Polyester/Fiberglass) passenger tire under severe conditions of high speed, underinflation, and overload designed to fail the tire after approximately thirty (30) minutes on the test wheel. Test conditions were: 16 psig. cold inflation pressure, 1750 lbs. load, 75 MPH speed, and test room temperature 100°F. Total test time was thirty-five (35) minutes. Photographs C and D show a clearly evident flaw developing on the rear side of the tire in the 90 to 100 range on the cumulative difference curve. Note that the changes taking place in the current scan curve, or unprocessed data, are small and give little evidence of localized heat buildup. The location of the flaw does not correspond with the highest peak on the current data display. The test was terminated at the time Photograph D was taken. The tire was cut and a shoulder separation approximately 1" in width was found at the indicated location on the circumference.

Figure 7 shows TFD data for another H78-15 Bias Belted (Polyester/Fiberglass) passenger tire tested under equivalent conditions except for the addition of a two (2) hour warmup period at 50 MPH. Total test time was twenty-five (25) minutes. The photograph sequence covers the last fifteen (15) minutes of the test. Photograph A indicates potential flaws developing in the 0 to 10 range and the 85 to 95 range on the cumulative difference display for the rear radiometer. Photograph B shows increasing development with an indication of a third possible flaw at location 145 to 150. Photograph C shows this third flaw crossing an 050 control limit, and Photograph D shows above limit flaws at both location 5 and location 145 to 150. The flaw at location 85 to 95 is still evident but has not as yet crossed the control limit. The test was stopped at this point. The existence and location of the three flaws (shoulder separations) were confirmed by cutting the tire. It can be seen that the changes taking place during the test in the current or unprocessed data curve display are small and do not give satisfactory evidence of flaw location, magnitude, or rate of development.

Figure 8 illustrates testing of a J70-15 Bias Belted passenger tire of experimental design under FMVSS 109 High Speed (Extended to Failure). The test was terminated after fifteen (15) minutes at 100 MPH and the photographs were taken over this time period. Photograph B shows a potential flaw developing at location 50 to 55. This flaw crosses a 020 control limit in Photograph C, and continues to increase in magnitude as shown by Photograph D. Cutting of the tire revealed a small separation at the indicated location. It is interesting to note that detection of this flaw would have been virtually impossible by examining only the current scan data in view of the very small amount of change which took place during the test period. Figure 9 is a photograph of a tire tested on the TFD and cut open at a point where a flaw was detected on the cumulative difference curve.

FIGURE 9

The testing capabilities of the TFD should permit applications in such areas as:

- R&D studies
- Quality control of new tire production
- Testing of tire carcasses before retreading
- Safety checks of tires in service

The TFD should be of real value to tire researchers as a tool to study the influence of design changes, compounding variations, and different manufacturing conditions on tire heat buildup characteristics. In the quality control area, the TFD should be a useful supplement to regular wheel testing to gain a better understanding of thermal changes taking place within the tire, and to detect flaws at an early stage of development. This could provide possible savings in wheel time. On a longer term basis, it may prove feasible to develop new high severity Q.C. tests as economical replacements for present long duration wheel tests.

The operating features and the unique computer controlled data system of the Monsanto TFD offer a greatly expanded utility to non-destructive infrared tire testing, and this new testing instrument should find wide acceptance by the quality and safety conscious tire industry.

QUESTIONS AND ANSWERS

Q: Your representation on your graph – is that an arbitrary figure?
A: After a period of time you begin to recognize particular formations of different types of failure and the limits were set pretty arbitrarily. As I say, based on experience in terms of looking at them frequently we can tell what we are going to get out of a particular waveform but we are also frequently fooled. Somebody mentioned this morning, I can't remember if they were talking about infrared, I believe it was, seeing a hot spot developing very quickly and then going away, we've seen that occasionally too, but I don't know what it is, but every once in a while we see one of those too. If I had to make a guess I'd guess it was a problem in adhesion that is occurring and then going through a remelt cycle and appearing back up again, but that is just a guess.
Q: It seems as if you should be able to look at the tire the very first moment that you start testing it and then from the heat buildup determine if there are any flaws present in the tire. I think we've asked this question a couple of times but we never got a satisfactory answer.
A: I think this is the approach you would have to use in order to apply this instrument for quality control test and I think it probably has to do with sensitivity and how rapidly you will see flaws developing.
Q: But it seems you have the sensitivity and you should be able to see this anomaly?
A: I think that in practice I would have to say that it usually takes a while running before you do see a flaw developing and at least, based on what we know now, I think we've run that too long to be used as field test.
Q: I think perhaps we've seen over a period of time, – let's just say for 3 revolutions, – enough to substantiate the potential flaw area?
A: We sure would like to be able to do that but at this point in time it has been our experience that we cannot.
Q: If you say a 1/2" separation in the tire initially. Apparently you can see the separation, the very small separation, that has developed after you have run the tire a long time, but can you see it there initially?
A: I think you would have to run the tire long enough to get that working in the tire to produce a measurable temperature at the surface that really differentiated that portion of the tire.
Comment from Floor: I agree that you can see flaws in the tire, we have seen flaws that are in tires initially, – but the conclusion is that there are a very few tires that have flaws built in that are not noticeable. It's mostly developed flaws later in the test that create problems.

CHAPTER VI – X-RAY TIRE TESTING

INTRODUCTION TO X-RAY TIRE TESTING

Ted G. Neuhaus, Chairman
Picker Corporation
Tire Systems
1020 London Road
Cleveland, Ohio

X-ray testing of tires in 1973 still maintained the number one position and preference of all existing NDT methods. An excellent measure is the yearly total approximate number of installations of complete tire x-ray systems worldwide. This is a difficult figure to accurately obtain, but the best estimates for 1973 indicate sales volume in the range of 45 to 50 systems. This number would not include updated systems of "homemade" systems. Now this figure may sound small and insignificant, but considering the dollar investment per system, between $100,000 and $250,000, the application and benefit must be justifiable.

We have asked ourselves as manufacturers and users of this equipment, why the increase demand and usage of x-ray systems? Generally speaking, these are the reasons:

1. The radial passenger and truck tire construction. Consumer ride acceptability and liability.

2. Inspection costs per tire reduced by availability of automated high production systems. Specifically automatic handling equipment.

X-ray tire testing is a growing field of inspection, and we all know that it will continue to grow.

Our next speaker is Mr. Dick Beeghly, Kelly-Springfield, Cumberland, Maryland.

X-RAY INSPECTION OF UNCURED (GREEN) TIRES AT THE KELLY-SPRINGFIELD TIRE COMPANY

R. M. Beeghly, Development Engineer
J. D. Hensell, Manager, Quality Control

Kelly-Springfield presently has eight (8) x-ray units being used to inspect uncured or unvulcanized passenger and light truck tires.

The units are located in the tire building areas of each of the company's four factories – Cumberland, Maryland; Tyler, Texas; Freeport, Illinois; and Fayetteville, North Carolina.

Figure 6 shows a green tire being mounted on the x-ray machine, Figure 7 shows the Quality Control technician viewing the TV monitor while inspecting a cured tire.

In addition, Kelly-Springfield has an x-ray machine in its truck tire inspection area and a unit in the tire test lab which is used for developmental purposes at the corporate headquarter's plant at Cumberland, Maryland.

The x-ray inspection of "green tires" is directed by the Quality Control Department in each plant.

The program is designed to accomplish the following:

1. Improve the quality of K-S tires.
2. Improve the skill of tire builders.
3. To recognize those builders who achieve an "outstanding" rating.
4. To assist in training new tire builders.
5. To maintain a high level of builder proficiency.

TIRE SELECTION

A tire from each builder is randomly selected from the production line each day. The tire is inspected and depending on its quality, a rating is established. If the builder's tire is rated below a set level, another tire is checked. If the second tire has a low rating, all of that builder's production for the day is inspected, and also any tires which have proceeded through the curing cycle are inspected.

The builder is informed of his problem and shown his tire on the x-ray machine.

Attachment No. 1 and 1A are the forms used by the Quality Control Inspector while performing the x-ray inspection.

Attachment No. 2 – Daily Summary – This printout lists the builders by number and name. It shows the number of tires x-rayed, the builder's rating for each tire and the date of x-ray. Also it gives the builder's average daily rating and an overall rating for a particular line of tire builders.

Attachment No. 3 – Monthly Summary – The monthly defect summary lists the number and type of irregularities found in all of the tires x-rayed from a particular builder for that month.

The tire builder with the highest monthly average is recognized as the "Outstanding Builder of the Month." A suitable gift is awarded him and an article is placed in the Company newspaper.

The daily and monthly summaries are also posted on bulletin boards in the tire building areas.

INSPECTION

The Quality Control Inspector checks each tire for the following conditions:

1. Beads
2. Chafers and flippers – wrinkled, wide or open splices.
3. Plies – piled endings, off-center.
4. Turn-ups – wrinkled, open splices, dop ears. (Figure 1)

5. Sidewalls – wide or open splices. (Figure 2)

6. Treads – open splices. (Figure 3)

7. Belts – step-off, splices, centering, dog ears, (offsets). (Figures 4 and 5)

Each component is built into the tire within specified tolerances. The Quality Control Inspector determines if the tire is built within the established specifications.

Tire abnormalities are classified as irregular or critical. Irregular is defined as those abnormalities that will not affect tire performance. A critical abnormality will affect the performance of a tire in that it will be unsatisfactory for esthetics (ride, appearance, etc.) or result in premature tire failure.

FIGURE 1
OFF-SET (DOG-EAR) IN PLY TURN UP WIDE PLY SPLICE

FIGURE 2
OPEN LINER SPLICE

SPECIFICATIONS

The specifications for this program are established by the Central Development Department at Kelly-Springfield.

Through past experience, field evaluation, controlled wear and durability tests, high speed road testing, and laboratory testing, tolerances are formulated.

The x-ray unit in the Test Lab at Cumberland is used to screen tires in establishing tolerances for this program.

BENEFITS OF PROGRAM

1. To the tire builder:

   a. The tire builder is motivated through recognition of "outstanding" performance.

   b. Builder skill is increased.

FIGURE 3
OPEN TREAD SPLICE

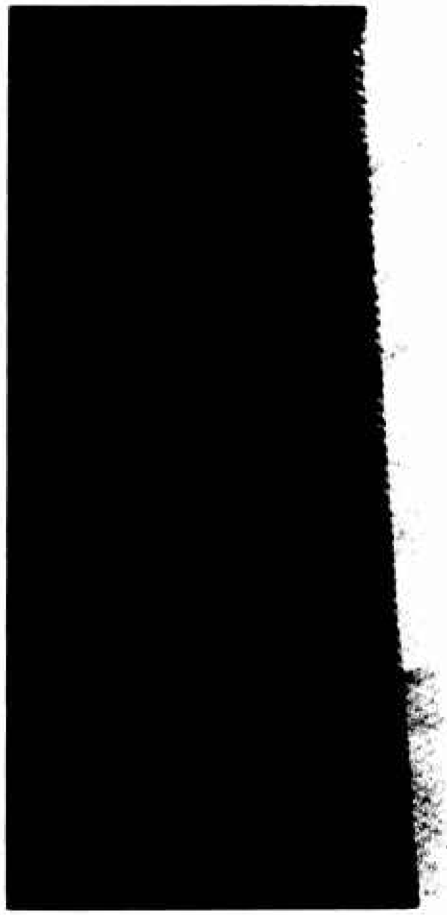


FIGURE 4
PILED BELT ENDINGS

c. Training of new builders and retraining of experienced builders is enhanced.

2. To Kelly-Springfield:

   a. A cost saving in that tires not built to specifications are stopped early in the production cycle.

   b. Problems are solved in the area where they occur.

   c. Reduction of certain classifications of customer complaints and return tires.

   d. Customer awareness of K-S concern for tire quality.

CONCLUSION

This program has been in progress for about 1-1/2 years. A before and after comparison is difficult to make because accurate data before the program was instituted is not readily available.

Kelly-Springfield management recognizes x-ray as a vital nondestructive testing tool.

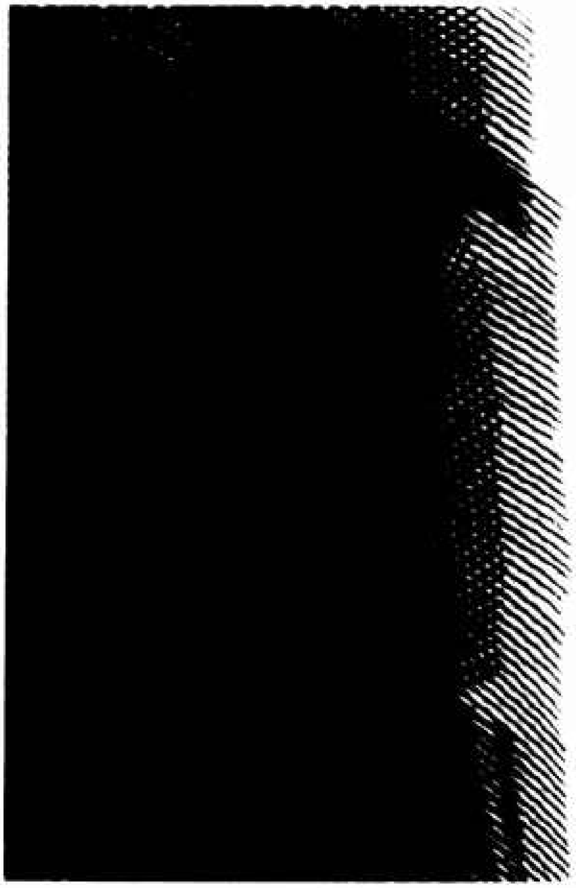


FIGURE 5
FOLDED BELT, WIDE SPLICE AND OFFSET IN STEEL BELT

FIGURE 6

FIGURE 7

ATTACHMENT – 1

X-RAY SUMMARY
BUILDER RECOGNITION PROGRAM

INSPECTOR ______________

TIRE TYPE

A. Pass-Bias
B. Pass Bias Belted
C. Pass Radial
D. Truck Bias
E. Truck Bias Belted
F. Truck Radial

DATE ______________
SHIFT ______________
PAGE ______ OF ______

SHIFT SUMMARY	TOTAL Bogey	TOTAL Back-up	IRREGULAR Bogey	IRREGULAR Back-up	CRITICAL Bogey	CRITICAL Back-up
Builder Recognition Tires						
Other Green X-Rayed						
Cured Tires X-Rayed						

Code	T.R.	Off Spec Cond.	M D	Bldr.#	Def. Code	I C	Col. 8	First Back-up	Second Back-up
									10
									20
		TOTAL							

REMARKS: ____

ATTACHMENT - 1A

DEFECT CODE LIST

Def. Code	Off Spec Condition
00	No Defect

BELT DEFECTS

Def. Code	Off Spec Condition
*01	Open belt splice
*02	Wide belt splice
*03	Stepoff
*04	Parallel belts (grouped angle)
05	Dogear belt splice
06	Short piece
07	Grouped cords
08	Spread cords (stretched, distortion)
09	Wrinkled belt
10	Missing cords
*11	Belt centering
12	Off coat belt stock
13	
14	
15	

LINER DEFECTS

Def. Code	Off Spec Condition
41	Open liner splice
42	Wide liner splice
43	Liner centering
44	Wrinkled liner
45	Trapped air
46	Damaged liner
47	

TREAD AREA DEFECTS

Def. Code	Off Spec Condition
61	Open sidewall splice
62	Wide sidewall splice
63	Wrinkled sidewall
64	Sidewall sets
65	Irregular tread splice
66	Trapped air
67	
68	

Def. Code	Off Spec Condition
00	No Defect

PLY DEFECTS

Def. Code	Off Spec Condition
*21	Open ply splice
*22	Wide ply splice
*23	Ply/Ply stepoff (piled turn-up)
*24	Parallel plies (grouped angle)
25	Dogear ply splice (turn-up)
26	Short piece
27	Grouped cords
28	Spread cords (stretched distortion)
29	Wrinkled ply
30	Missing cords
31	Open turn-up splice
32	Wide turn-up splice
33	Off coat ply stock
*34	Ply/flipper stepoff
*35	Ply ending
36	Wrinkled turn-up

BEAD AREA DEFECTS

Def. Code	Off Spec Condition
51	Kinked beads
52	Loose turn-ups
53	Trapped air
54	Chafer/flipper wrinkles
55	Chafer/flipper open splice
56	Chafer/flipper wide splice
57	

MISCELLANEOUS DEFECTS

Def. Code	Off Spec Condition
*71	Missing component
72	Wild cord
73	Foreign material
74	
75	
76	
99	Miscellaneous

OC010-100-961 MONTH JUNE 1974 **G R E E N   T I R E   X - R A Y** SHIFT 3 PAGE NO.12 6/26/74

NO.	BUILDER	(A) 1ST	2ND	3RD	4TH	5TH	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH
336	R CRISSL (B) (91.1)	100- 3	100- 4	100- 5	100- 6	80-11	100-13	80-19	80-25	80-26						
337	P NATALE (88.6) (C)	60-10	100-15	80-18	100-19	100-20	100-25	60-26								
338	R PECK (97.8)	(D) 100- 1	100- 3	100- 4	100- 5	100- 6	80-11	100-14	100-15	100-25						
339	K E HARDMAN (94.7)	80- 3	100- 3	80- 4	100- 5	100- 7	100- 7	100-11	80-13	100-14	100-15	100-18	100-[illegible]	100-22	100-25	80-2[illegible]
340	E FELTEN (90.0)	80- 5	100- 5	100- 7	80- 7	100-10	60-14	100-15	100-18	100-20	80-25					
345	T L DETRICK (97.1)	100- 3	100- 4	100- 5	100- 7	100-10	100-18	80-21								
346	K L HARTMAN (91.1)	80- 4	80-10	100-14	100-15	100-15	80-18	100-21	80-25	100-26						
347	T L GREEN (100.0)	100- 3	100- 4	100- 6	100-11	100-19	100-20	100-21								
348	P PHILLIPS (100.0)	100- 3	100- 4	100- 7	100-13	100-18	100-19	100-20	100-21	100-25	100-26					
349	J W LOGSDON (95.0)	100- 7	100-10	100-19	80-25											
350	L BLANK (96.7)	100- 4	100- 5	80- 6	100- 7	100-11	100-20									
351	R WILSON JR (95.0)	100- 3	100- 5	80- 7	80-10	100-13	100-14	80-15	100-19	100-19	100-20	100-21	100-25			
352	T T DORRILL (90.0)	80-15	100-19													
353	S GUY (93.3)	80- 3	100- 4	100- 5	80- 7	100-18	80-19	100-21	100-25	100-26						

(E) OVERALL RATING FOR LINE = 94.5

ATTACHMENT – 2

A – NUMBER OF TIRES X-RAYED
B – BUILDER IDENTIFICATION
C – CURRENT MONTHLY AVERAGE
D – RATING PER INDIVIDUAL TIRE AND DATE X-RAYED
E – OVERALL RATING FOR ALL BUILDERS

MONTHLY X-RAY DEFECT SUMMARY - BUILDER DETAIL
SEPTEMBER 1973

ATTACHMENT - 3

BUILDER NUMBER	NAME	TOTAL CHECKED	DEFECT CODE	NUMBER IRREGULAR	NUMBER CRITICAL
114	G R YONKERS	(CONT'D)	DOGEAR PLY SPLICE	2	0
			SPREAD CORDS (BELT)	1	0
			SHORT PIECE (PLY)	1	0
			WRINKLED PLY	1	0
115	C P LAYTON	12	SHORT PIECE (PLY)	1	0
			OPEN LINER SPLICE	1	0
			DOGEAR BELT SPLICE	1	0
			WIDE PLY SPLICE	2	0
			DOGEAR PLY SPLICE	1	0
116	J SAVILLE	29	WIDE PLY SPLICE	2	0
			DOGEAR PLY SPLICE	1	0
			SPREAD CORDS (BELT)	1	0
117	J WRIGHT	19	DOGEAR BELT SPLICE	1	0
			OPEN PLY SPLICE	1	0
			WIDE TURN-UP SPLICE	1	0
			WIDE PLY SPLICE	2	0
118	K DEFFINBAUGH	23	DOGEAR PLY SPLICE	2	0
			OPEN TURN-UP SPLICE	1	0
			SHORT PIECE (PLY)	1	0
			WIDE TURN-UP SPLICE	1	0
			WIDE PLY SPLICE	1	0
119	G MILLER	28	OPEN TURN-UP SPLICE	2	0
			SPREAD CORDS (BELT)	1	0
			DOGEAR BELT SPLICE	1	0
			WIDE TURN-UP SPLICE	1	0
			WRINKLED LINER	1	0
			WIDE PLY SPLICE	1	0
			SHORT PIECE (BELT)	2	0
120	M MATTINGLY	26	OPEN TURN-UP SPLICE	2	0
			OPEN LINER SPLICE	3	0

NEW IMAGING APPROACH TO TIRE INSPECTION

Robert C. Fiorille
Presented by Mr. Robert Belin
Imagex, Inc.
Mentor, Ohio

The production rate of tires requires an imaging presentation for X-ray inspection at a matching rate. This paper described a new three-screen simultaneous image of the tread and both sidewalls of a wide range of tire sizes in a single image real-time display which is coupled to a high speed tire handling system. (Paper not released for publication.)

PRODUCTION TIRE X-RAY SYSTEMS

Ted G. Neuhaus
Picker Corporation
Tire Systems Division
1020 London Road
Cleveland, Ohio 44110

Last year we presented the paper "Automatic X-Ray Systems for Tire Inspection". The material presented therein contained considerable information regarding prototype production x-ray systems which, in effect, seemed to be theoretically feasible, but had not been given sufficient time to prove their operation in a typical production climate.

We are pleased to say, and with confidence, that the concepts presented are now operating reality with minimum down time. These concepts specifically were the:

1. AID Production X-Ray System. (Air Inflated Device)

2. 10/27/750 Production X-Ray System for intermix range, computor controlled, from bead diameters of 10 through 27 inch to 750 pound tires.

Both of these systems have the capability of bead-to-bead inspection with one x-ray tube and one generator.

Slide 1 – It is interesting to note that the standard systems, the "ole workhorses" are still very much in demand.

Slide 2 – The *belt only inspection system* concept was supplied, and is still used quite heavily, but the demand today appears to be for a versatile unit to inspect bead-to-bead. Not just belts as this pictured concept.

Slide 3 – Again, in review, the AID production x-ray system was presented last year as shown in this slide. A method of simple conveyance of the tire was required whereby the delivery could be presented to the machine in the horizontal and "dumped" into the vertical acceptance of the machine. Likewise, exited in the vertical after classification by the operator, and removed to an existing plant horizontal conveyor. Emphasis should again be made that the reason for designing the AID machine in the vertical inspection mode was to maintain as near perfect a centerline of rotation as possible. This condition dictates accurately placed vertical fixed rims with inflation and no weight contribution to sidewalls from horizontal dropout. Another requisite was the ability to make the entire system transportable by fork lift truck to a new location within the plant.

Slide 4 – Our concept to accomplish these features was presented in the next slide. The primary consideration was to give emphasis upon radiation safety to the surrounding plant personnel. The AID system keeps radiation on the x-ray tube at all times during entrance and exiting of the inspected tire.

Slide 5 – This slide shows the AID system, as shipped today, with the operator console, viewing window to the radiation enclosure, and the video measuring micrometer on the table. The purpose of the video micrometer, which is adaptable to all fluoroscopic television systems, is to provide the operator an instrument which is selective to any portion of the television monitor screen to make accurate measurements of the tire construction, and with digital presentation. Measurements can be made to any belt area – stepoffs, belt width, degree of snaking, turnup height, splice width, bead bundles, etc. The total production floor space consumed is only 7 x 9 x 10 ft.

Slide 6 – Different view of input and output tunnels.

Slide 7 – Again, in the paper presented last year, this slide was presented strictly as a concept for a machine that would meet the growing demands of production x-ray intermix of random size tires – passenger, truck, bus and aircraft.

10/27/750 SPECIFICATIONS

1. Automatic load and unload truck, bus, passenger, and aircraft tires.

2. Must have image quality and geometry as other tire x-ray machines.

3. Completely automatic tire handling system interfaced to the customer's conveyor.

4. Must intermix any and all sizes in any combination within the specification limits.

5. Must handle a wide range of tire sizes.

   a. Tire weight – 750 lbs maximum

   b. Bead diameter – 27 inches maximum, 10 inches minimum

   c. Tire outside diameter – 54 inches maximum, 10 inches minimum

   d. Tire width – 20 inches maximum, 6 inches minimum

   e. Bead width – 3.5 inches maximum

   f. Toe-to-toe distance – 1.25 inches minimum

   g. Heel width – 20 inches maximum

   h. Load/unload cycle time – 17 to 21 seconds

Slide 8 – This is the control console showing the Texas Instrument 960A computor, not controller, at the extreme right, fault analysis readout panel directly beneath, generator controls in the center, and operator television readout with tire grading pushbuttons. Directly beneath the monitor are the manual control pushbuttons for the inspection scan.

Slide 9 – Control console without overhead lighting showing lighted control function switches.

Slide 10 – Next to the control console is the power panel for easy servicing. 13 D/A converters provide up to 13 analog outputs to motor drives. There are separate solid state SCR motor drives for each DC motor driven function. Considering the typically noisy industrial electrical environment, precautions have been made to shield all input and output leads and the analog inputs filtered. The T.I. 960A computor with its storage capacity of 12,000 bits provides the tire company with an almost limitless range of tires for input to the system.

The operator may interrupt the automatic computor program at any time and take over manual control. The lighted control button functions will sequentially light, as shown, and assist the operator with a "lead-thru". The machine is actually protected from the operator.

Slide 11 – Shown in this slide is the binary fault analysis system. This is again an indirect benefit of the computor storage. The lighted readout will direct the operator immediately to one of 125 subsystems that might malfunction.

Slide 12 – All mechanisms are mechanically and electrically independent of each other. This provides independency and simultaneous functions reducing cycle times and improving flexibility to changing tire dimensions. This slide shows the independent mechanical motions used to position the manipulator conveyor to the centerline of the cross section of the incoming tire so as to provide exact insertion of the x-ray tube relative to the tire torus center.

Slide 13 – The most accurate method to date for maintaining true centerline of tire rotation is air inflation with fixed rim support to the beads. This is done in our AID system bead-to-bead. However, we have to compromise for flexibility of intermix. This slide shows the method of mounting in the 10/27 intermix using four spindles on top and four spindles below. No dependency for mounting or rotation is placed upon the tread. Considering, placement of a Lighthouse tube plus eight spindles into a minimum size tire of less than ten inches, this is an engineering accomplishment.

The automatic program sequence for the 10/27 system is as follows:

1. Measures the tire.

2. Brings tire into room and mounts on spindles.

3. Inserts x-ray tube into the tire with the x-ray tube focal spot at the bead diameter.

4. Positions the imaging system so that center of rotation is at focal spot.

5. Turns control over to operator to scan and make judgement.

6. Unloads the tire at operator request and loads new tire.

7. Allows operator interrupt at any time.

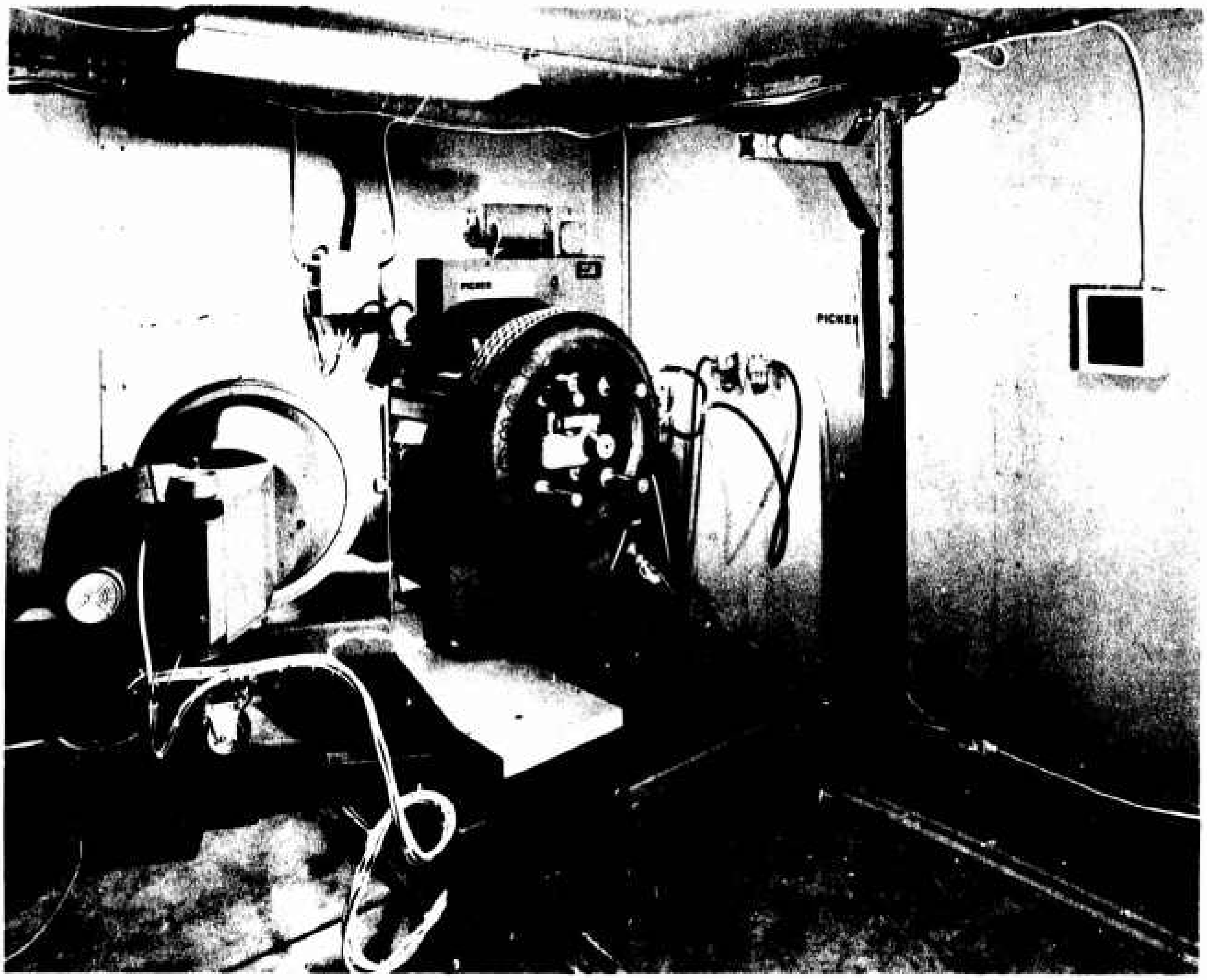
Continued expansion of computor capability will be developed. This would include the possibility of:

1. Automatic daily printout of inspection results categorizing to tire type, size, defect location, and resultant grade.

2. Preprogrammed television reference lines as guides for inspection of bead-to-bead programs.

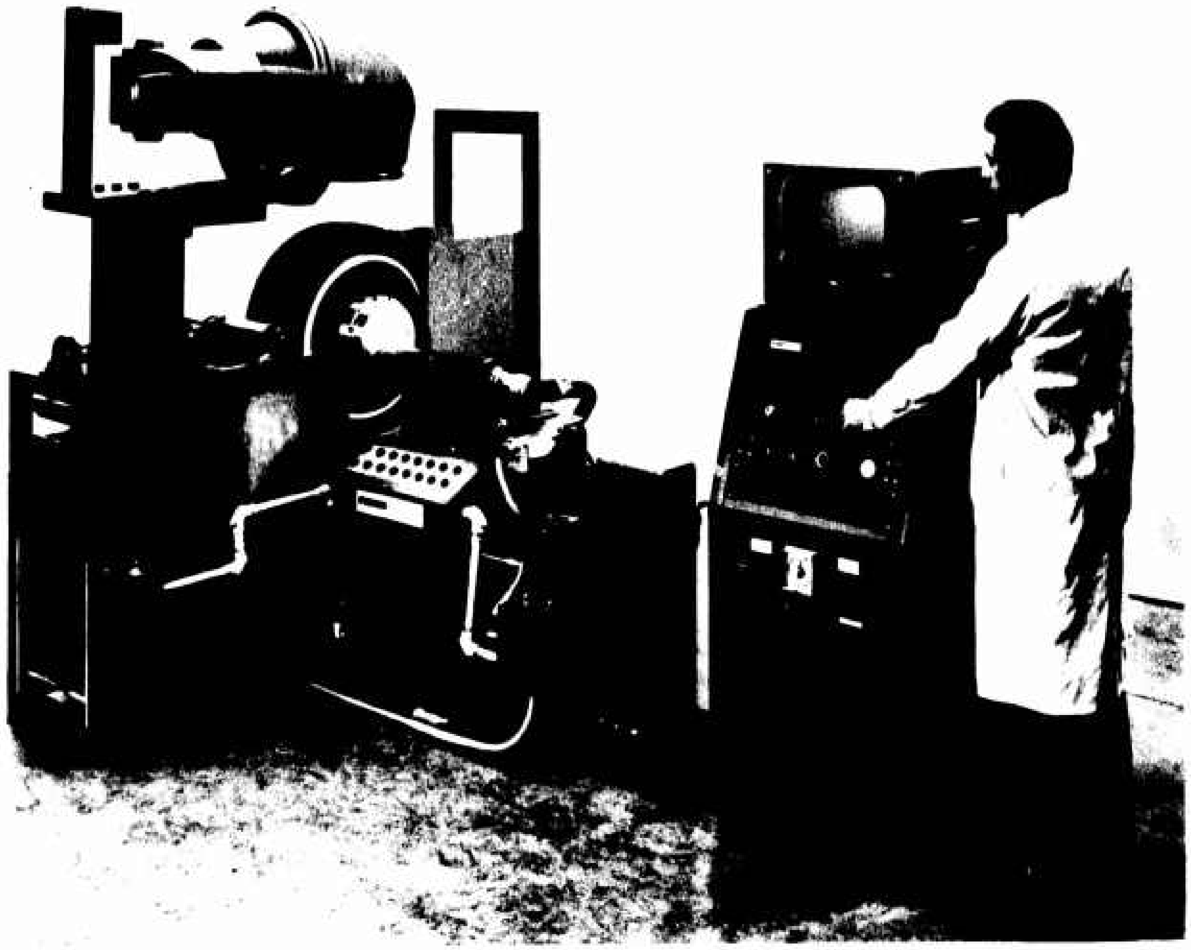
The following movie will display dynamically one of the six systems produced within the last year.

Thank you for your attention.



SLIDE 1

SLIDE 2



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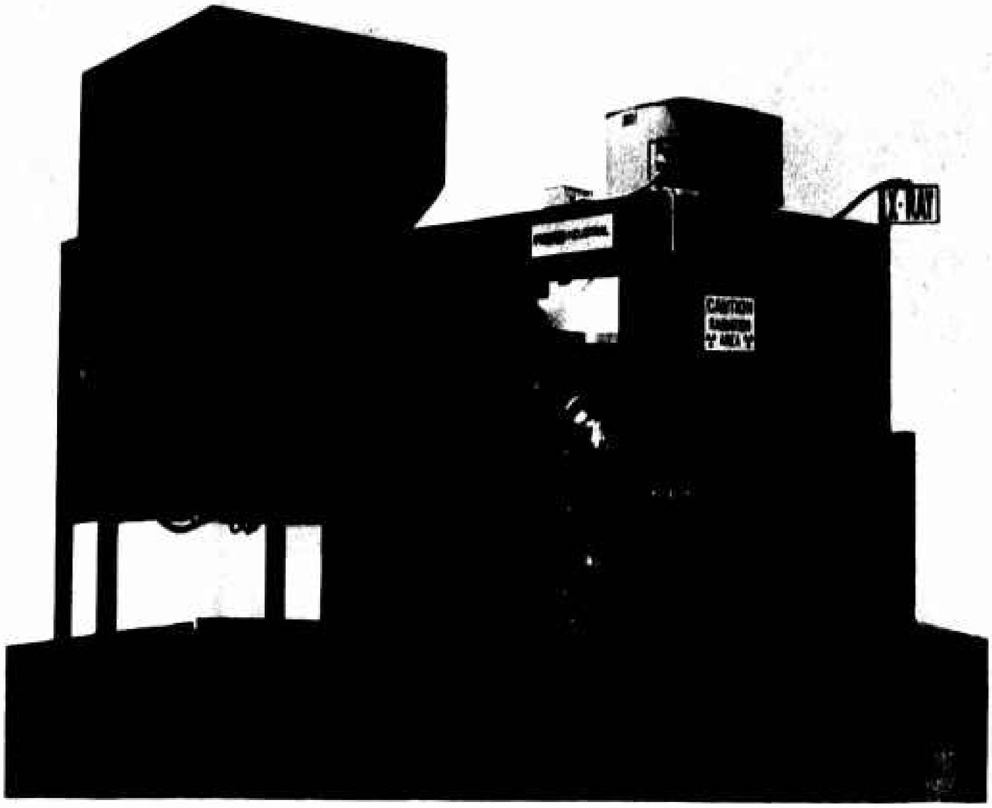
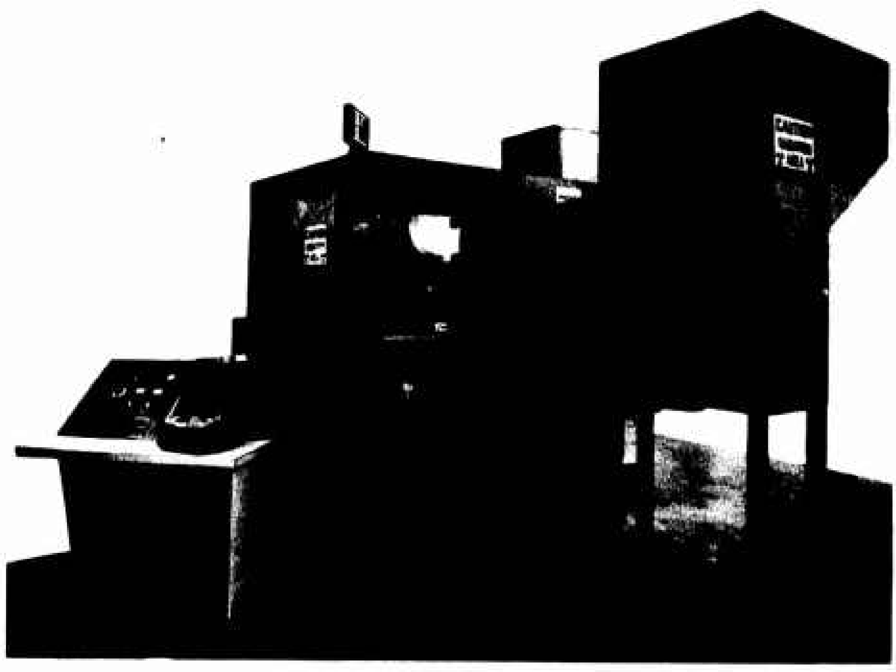


SLIDE 4



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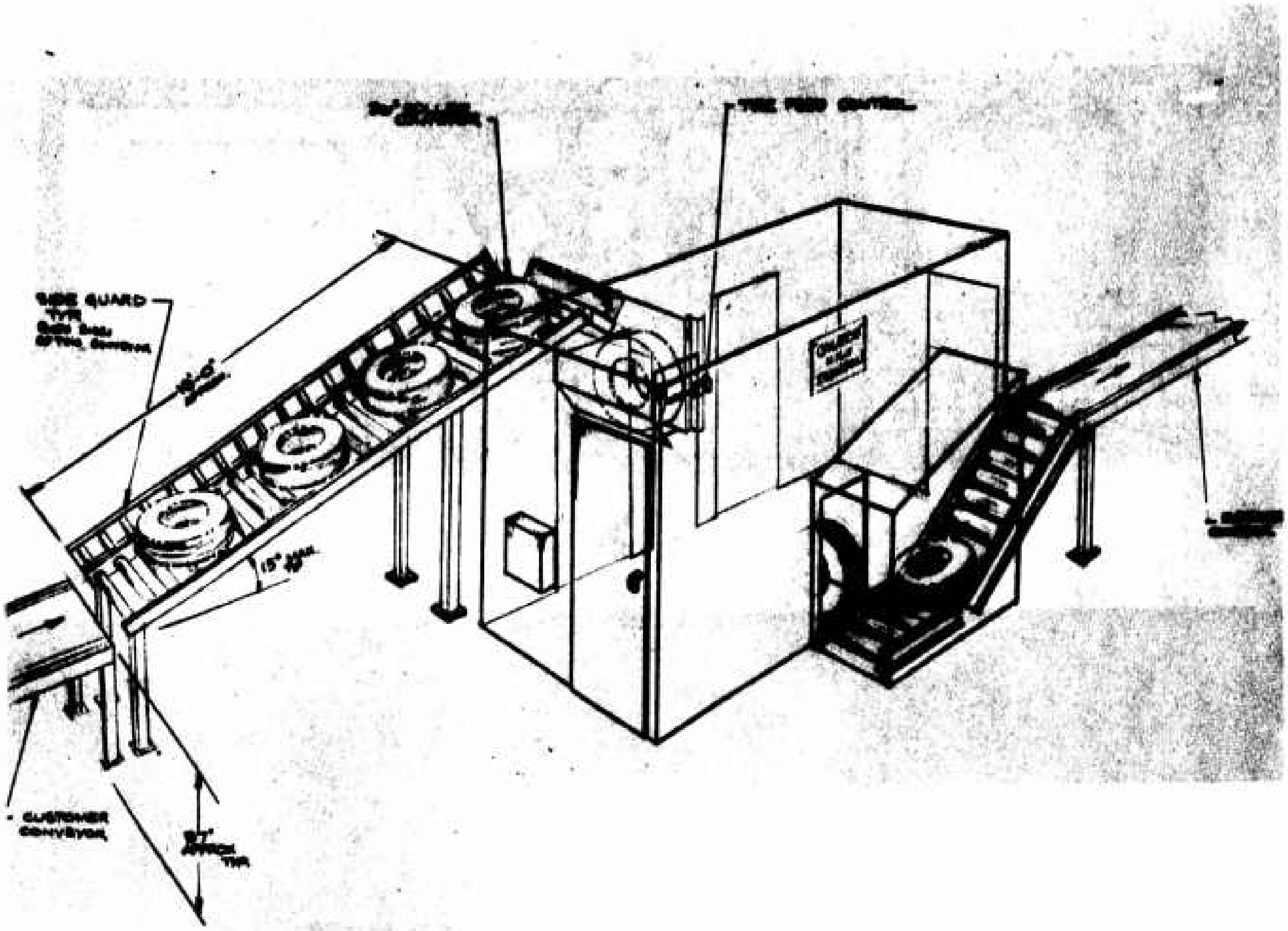

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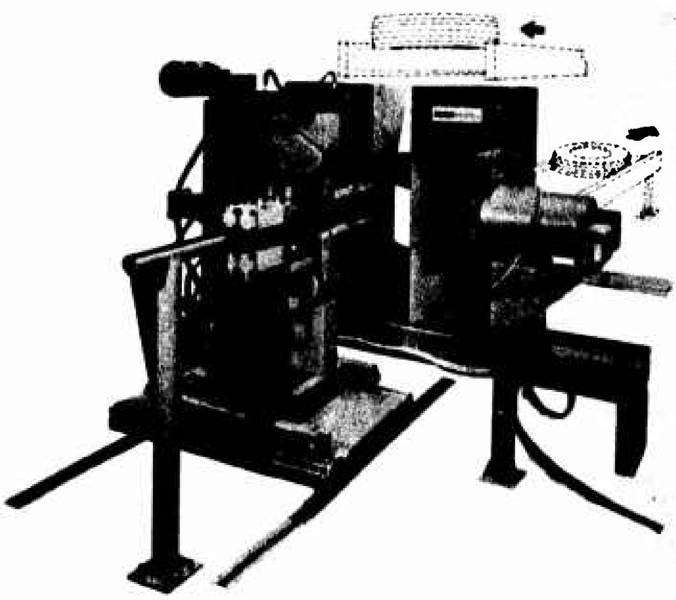

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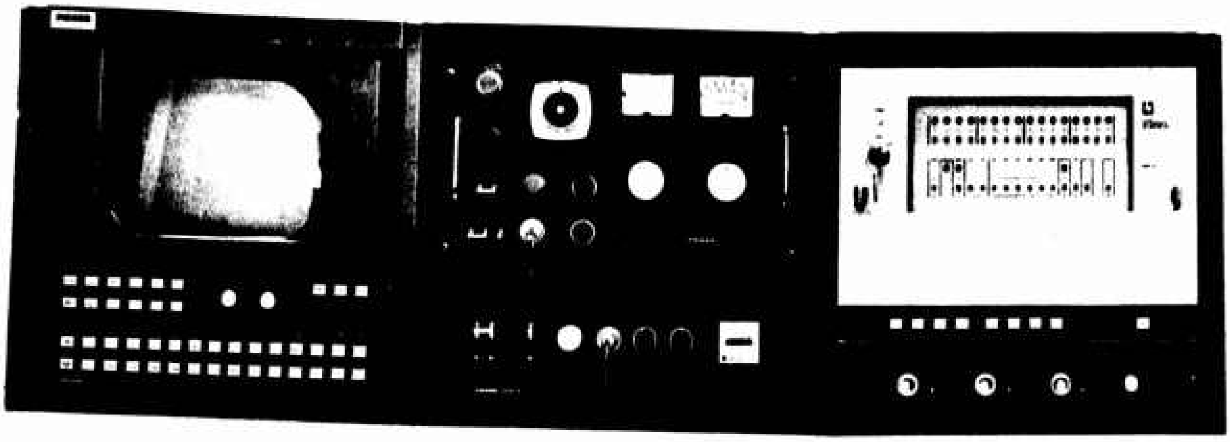

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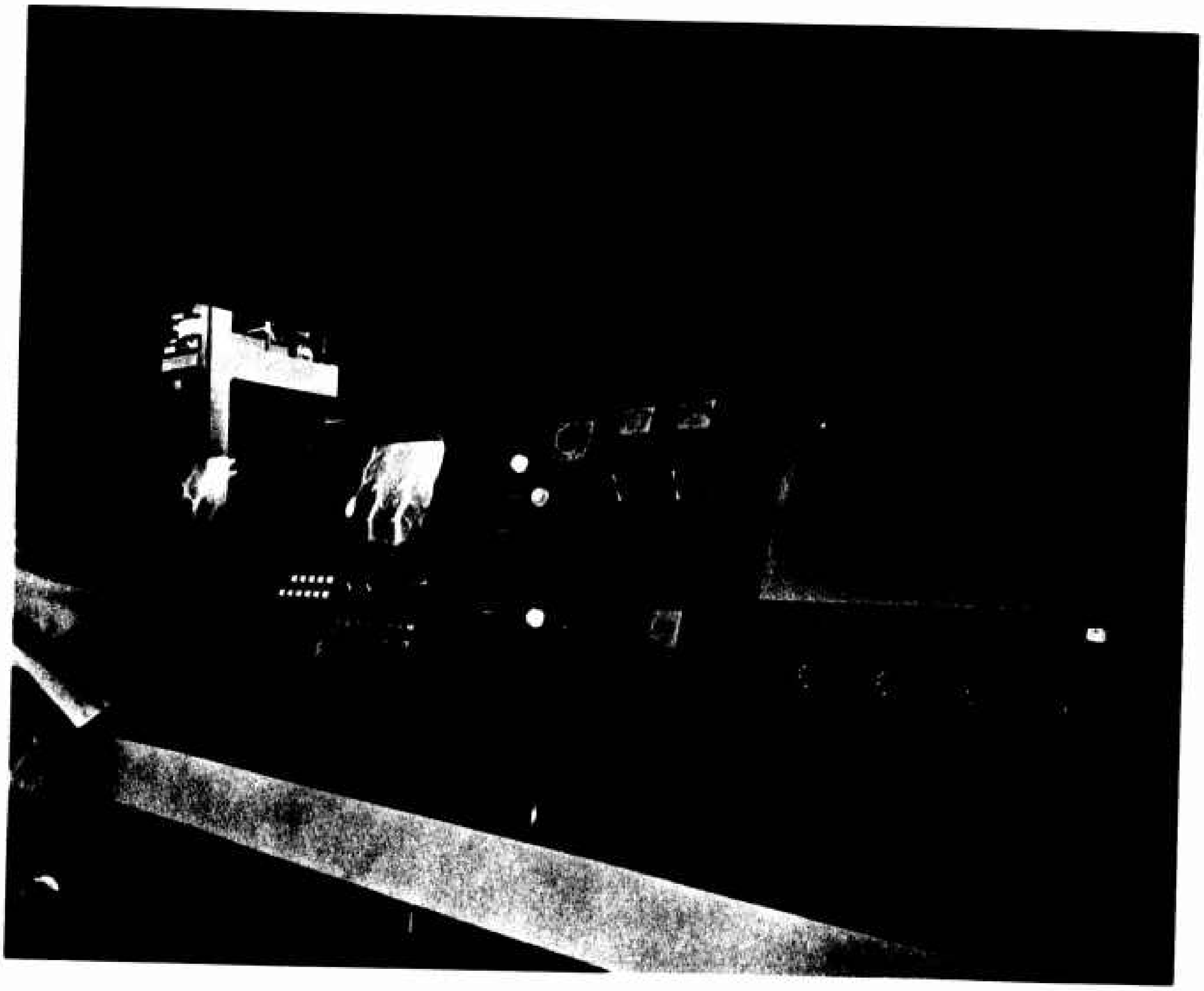

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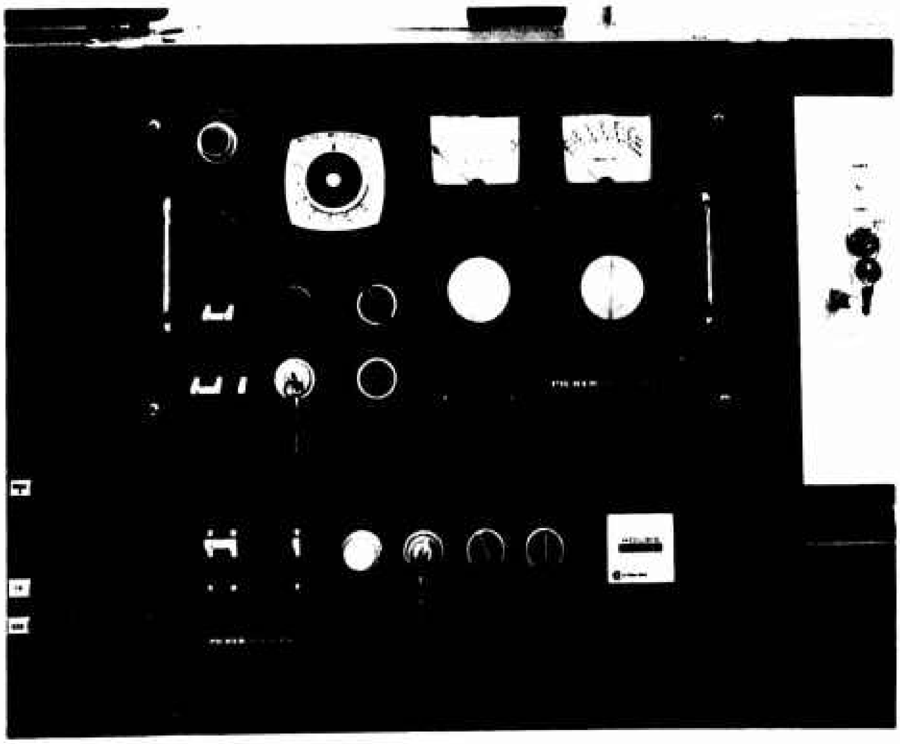
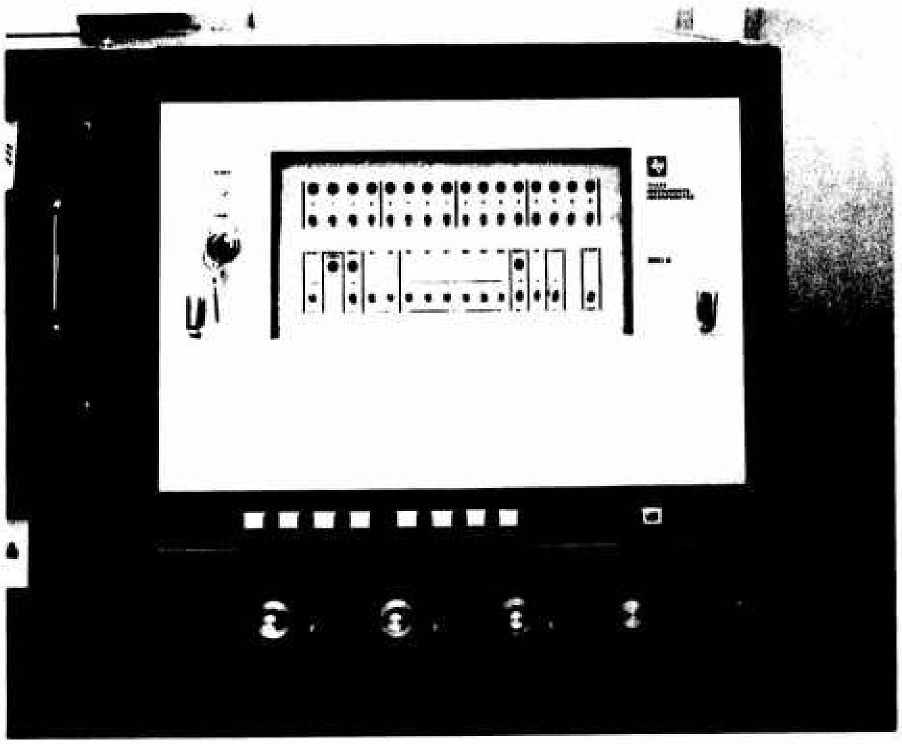


SLIDE 10



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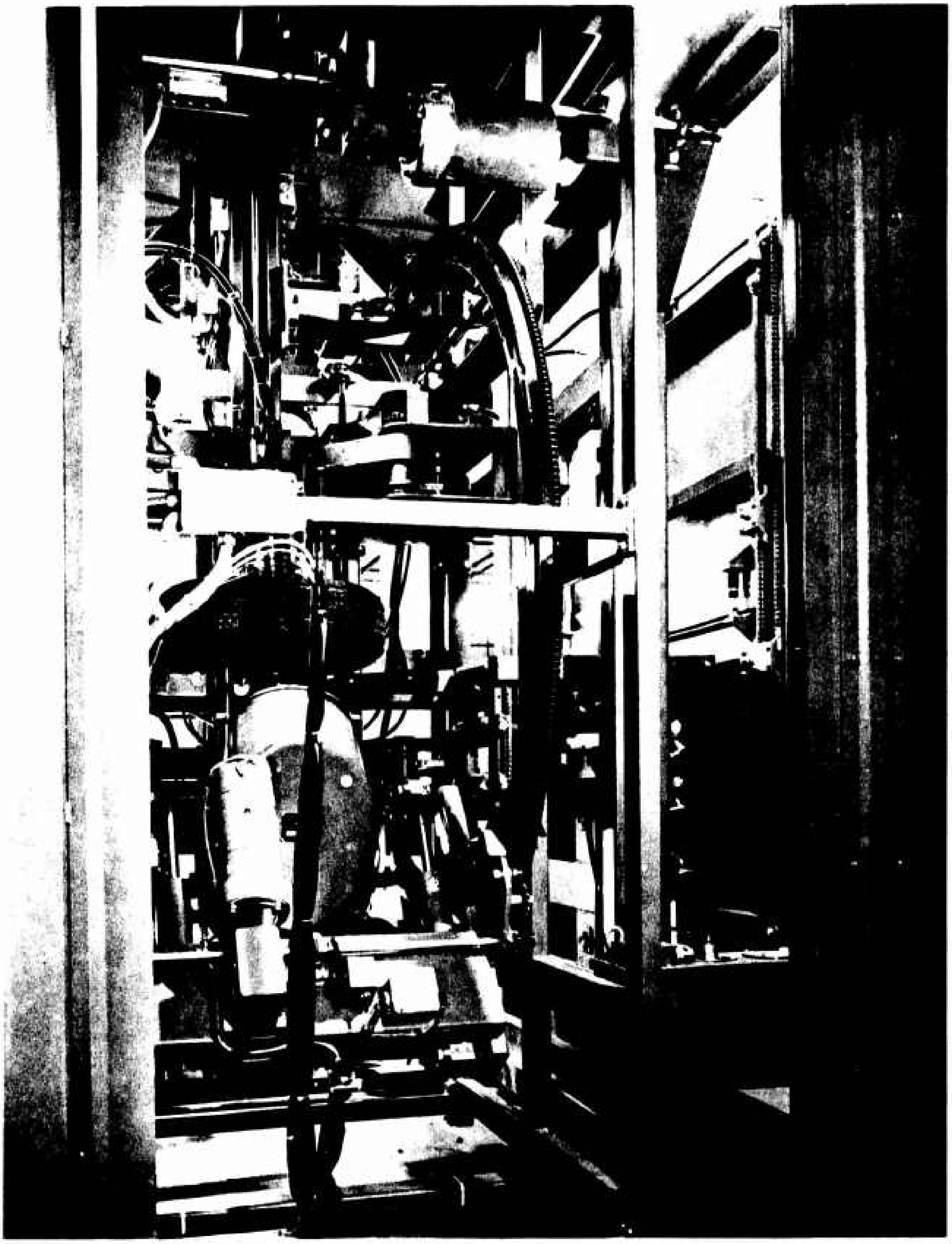

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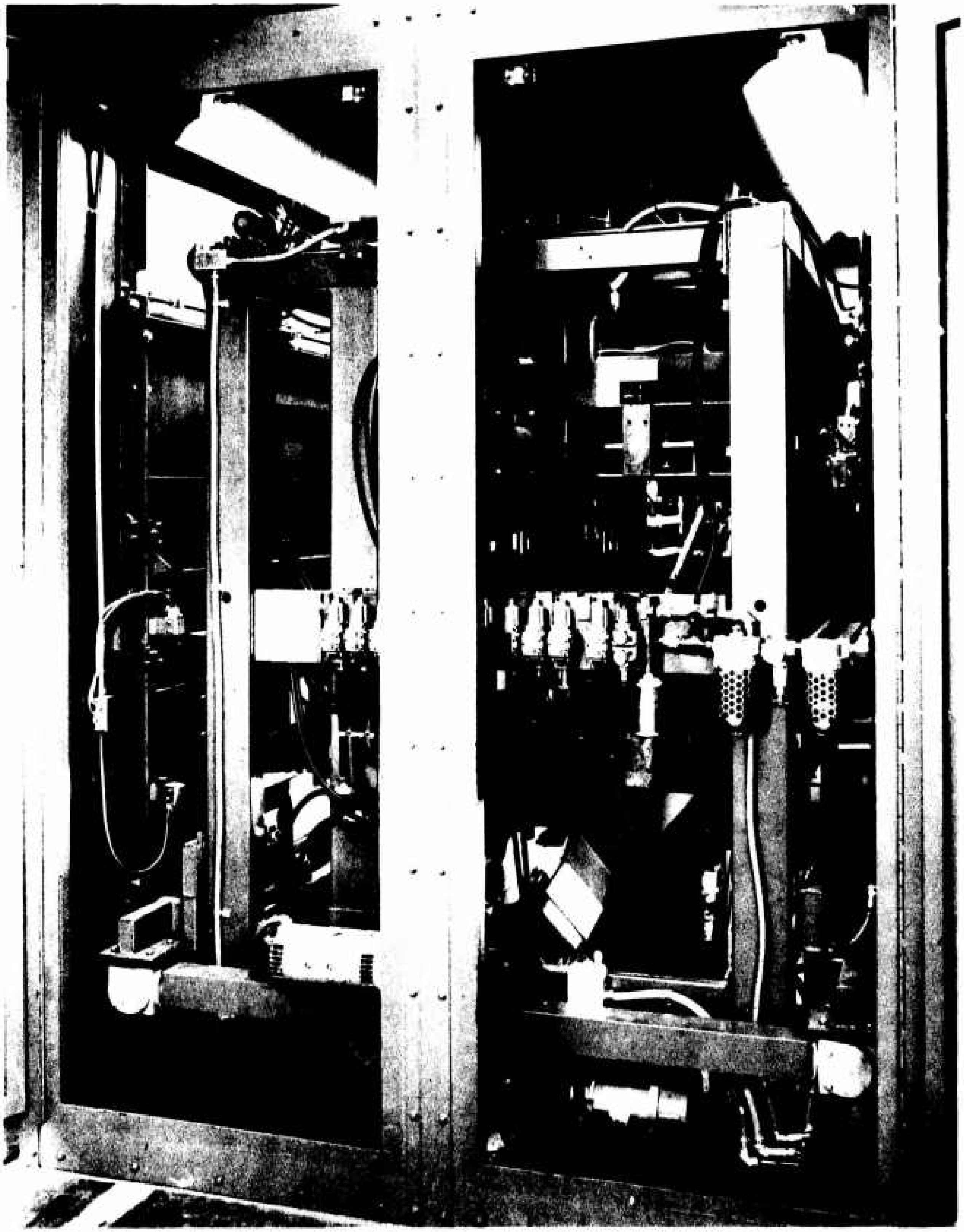

SLIDE 13

CHAPTER VII – ULTRASONIC TIRE TESTING

INTRODUCTION

Gwenn K. McConnell, Chairman
Naval Air Development Center
Warminster, Pennsylvania

Good morning. There's an expression in Atlanta and it takes 3 forms. It's most popular here and you hear it every place you go and it goes something like this, when you leave an establishment "you all come back now you hear" and the 2nd form is a little abbreviated, "you all come back" or 3rd, just "come back". Anyhow, I'm real pleased to see that so many of you all did come back to the 2nd symposium. We'll take just a few minutes of your time. Paul asked me to warm up the PA system for the ultrasonic speakers. Since our last tire inspection symposium, the energy situation, inflation, the ever increasing problem of used tire disposal have all impacted on the subject at hand. The military is and has been operating under an exhausted defense structure to make maximum use of aircraft tire rebuilding. Our Navy leadership in Washington has the jump on today's situation. The Navy program has progressed well. We are successfully flying fighter aircraft tires which were never rebuilt in the past and we have experienced better than new tire performance with many of our rebuilt tire sizes. An outstanding example of our precision flying team, The Blue Angels, have requested rebuilt tires exclusively because of their superior performance. Our program is supported by the application of nondestructive inspection as we require 100% inspection of all our high speed, high performance aircraft tires. At present the primary application is in detecting separation flaws.

We must investigate the capabilities of nondestructive inspection methods to detect signs of advanced degradation because as you know all failures are not related to those flaws. As we attempt to make maximum use of tire carcasses for cost and energy saving reasons, the need for additional quality assurance through nondestructive testing is anticipated. Similarly, radial type or road tires must allow for retreadability after rolling 40,000 miles. A nondestructive method of indicating carcass fatigue is needed. During the past year or so our work with reflection ultrasound has demonstrated applicability to a number of problems related to tires and similar products. To briefly mention a few, we can measure tread and sidewall thickness, liner thickness within ± 3 or 4 thousandths of an inch, measure the depth in spacing of steel radial wires, automatically control a buffing machine to give uniform undertread rubber thickness and I'm sure this is just a beginning to many areas where ultrasound will contribute to a successful use of critical mechanical rubber parts. Both theory and initial lab work indicate high potential for the measure of carcass degradation with reflection ultrasound. In summary we have just scratched the surface of the tire industry with a well established problem solving tool.

RECENT DEVELOPMENTS IN ULTRASONIC TIRE INSPECTION USING SONDICATOR TECHNIQUES

J.J. Lance, S.T. Mrus and H.E. VanValkenburg
Engineering Department
Automation Industries, Inc.
Danbury, Connecticut
Presented by Mr. VanValkenburg

The technical background of the application of Sondicator techniques to tire testing was described at the 1973 Symposium and reported in the published proceedings. This discussed the methodology, advantages and limitations of pulsed wave-train, low frequency (25 KHz), air-coupled sonic testing. While this approach has proved effective for inspection of smooth tread, such as typical aircraft tires, difficulties were found in applying it to vehicular tires having ordinary traction tread or lug surfaces. Because of the large difference in sound velocity between air and rubber, severe beam diffraction and interferences result. In simple geometries, e.g., regular cross-lug pattern, the signal variations could be reduced by mechanical gating of the system. Such an approach was investigated and proved feasible under sponsorship of U.S. Army Tank-Automotive Command. Automation Industries then proposed an alternative solution to the tread geometry problem which utilizes a dual coupling method.

Conventional Sondicator air-coupled probes are used inside the tire body where water is to be avoided, because of removal and drying requirements, as well as erratic wetability due to release and sealant residues. Water coupling, with the advantages of tread interference reduction and improved transmission efficiency is used externally, where it is not deleterious. Initial tests of an experimental setup were performed on 6.00 x 16 lug-type vehicle tires, also with the support of the Tank-Automotive Command. Tread "noise" suppression was almost total and discontinuities less than 1 sq. in. were detectable. Subsequently, a variety of tire constructions and tread geometries were investigated to determine the effectiveness and limitations of the method.

These brief comments will serve as an introduction to the following papers in which Automation equipment will be discussed.

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ULTRASONIC TIRE INSPECTOR

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and

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INTRODUCTION

The large volume of tires used on DOD vehicles necessitates an extensive recapping program within DOD (and especially within the Army). A simple low cost, reliable method of determining the integrity of a tire carcass prior to the retreading operation is very desirable because considerable expense can be avoided by not retreading faulty tires.

At present, truck tires are selected for retreading on the basis of a visual inspection and classification technique which culls out all apparent defects. However, there is no method available to detect internal defects. The tires are then sent to a retreading facility, either government or commercial. There, they are buffed (subjected to a grinding procedure to remove the old tread). During the buffing operation, the operator detects separations by sound, and rejects the tires possessing separations. This operation is extremely costly, since the tires must be transported to the retreader, transported back if the retreader is a commercial contractor since disposition by him is unauthorized, and the costly buffing operation must take place prior to rejection. In an effort to provide a solution to this inspection problem the Product Assurance Directorate (AMSTA-Q) and the Maintenance Directorate (AMSTA-M) of the Army Tank Automotive Command are cosponsoring a program to develop an ultrasonic inspection system, which will nondestructively determine whether or not used tire carcasses have defects in them.

TIRE CONSIDERATIONS

There are many nondestructive inspection methods presently being applied to tires: X-radiography, Infrared, Holography, and Ultrasonics. All of these methods are capable of detecting defects in tires. However, Ultrasonics seems to best fulfill the Army requirements of low cost and simple application.

There are a number of ultrasonic techniques and frequencies available for inspection. But, to maximize resolution and sensitivity, and ultrasonic tire test system should operate at the highest practical operating frequency. The highest possible operating frequency can be obtained by using a two transducer thru-transmission system because of the lower attenuations involved in a single pass through the tire. However, the inherent simplicity of a single transducer pulse-echo system together with its depth discrimination capabilities makes pulse-echo a more attractive method. It is further attractive since time gating the reflected ultrasonic signal helps allow the inspector to ignore the signals induced by varying tread geometries.

The area we inspect, prior to retreading, is the plys in the casing of the tire. It is in this area that the ultrasound must be induced and monitored during production testing. While superficially this sounds like a relatively easy problem, it is complicated by variation in tread and carcass rubber, whether the casing is an original or a retread tire, and changes in geometry (carcass eccentricity, tread runout, etc.).

INSPECTION SYSTEM

An ultrasonic pulse-echo inspection system was developed which incorporated the transducer positioning requirements to inspect a range of tire sizes (7:00 x 16, 9:00 x 16, 9:00 x 20, and 11:00 x 20). The inspection system has power tire mounting and rotation features, and incorporates a modified ultrasonic inspection unit.

The inspection system developed is shown in Figure 1. Briefly, it contains an immersion tank necessary to couple the high frequency ultrasonic energy into the tire. Figure 2 is a photograph of the transducer and fixturing required to inspect the five tire sizes previously mentioned. The transducer is mounted to an angle manipulator which permits setting of the transducers incidence angle to the inspection surface of interest in the tire. The manipulator is attached to a set of sliding cross-ways which allows for adjustment of the height of the transducer to the inspection surface and X-Y positioning for the various size tires. The cross-ways are mounted on a cradle which can be positioned to inspect the five most critical areas of inspection (i.e., sidewalls, shoulders, and tread). It can also be adjusted to inspect the remaining portions of the tire.

FIGURE 2
PHOTOGRAPH OF ULTRASONIC TRANSDUCER AND FIXTURING

The tire handling equipment shown in Figure 3 consists of a modified Branick Tire Spreader and a Southworth Pneumatic Lift Table, with a rotary bearing to allow tire angular motion.

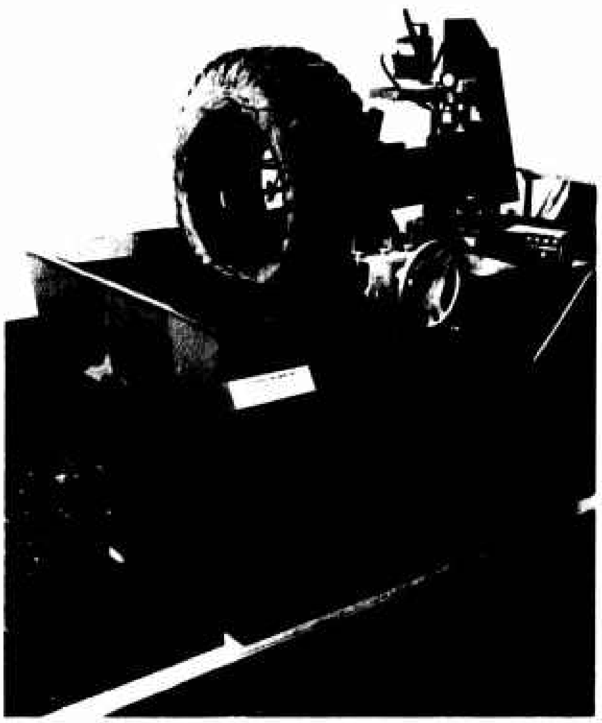


FIGURE 1
PHOTOGRAPH OF ULTRASONIC INSPECTION SYSTEM

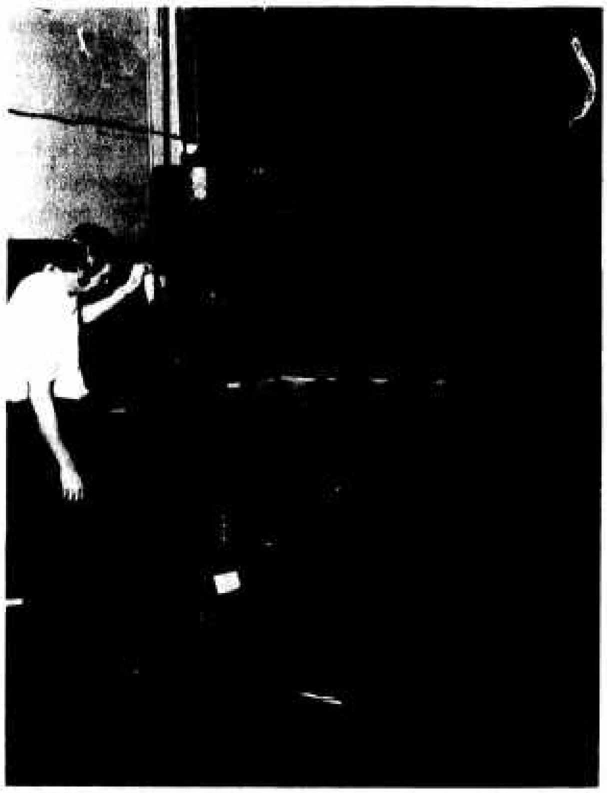


FIGURE 3
PHOTOGRAPH OF TIRE HANDLING EQUIPMENT

The tire handling procedure developed is straightforward and was made so with a field inspection in mind. The operational procedure is as follows: First, the tire is rolled onto the air operated lift which allows the casing to be raised slightly above the inner bead hooks. The inner bead hooks move laterally outward to engage the inner bead of the casing. The spreader uses six inside arms to engage the outer bead casing. These arms are controlled by the main air cylinder and will move outward to spread the tire to any desired width.

Following the mounting of the tire onto the spreader, it is lifted above the water tank walls, rotated 90 degrees, and lowered into the water tank. The tire is then ready for ultrasonic inspection. The above procedure is reversed to remove the tire from the system.

The ultrasonic inspection equipment used is a modified Sonics Mark I ultrasonic inspection unit. This unit was readily available commercially and has most of the operational characteristics required. Test had shown that a high powered pulser, coupled to a broad-band receiver, was required to provide sufficient signal for the inspection of 12-ply rated tires. Therefore, a 1200V pulser and a 0.1-1.0 MHz broadband receiver were incorporated into the unit.

FIELD TESTING

After developing the proper inspection techniques in the laboratory, the inspection system was field evaluated at Red River Army Depot (RRAD). With the help of RRAD personnel, it was possible to inspect tires and verify the results obtained with destructive analysis or with the current inspection procedure during buffing.

The primary interest was to evaluate the ultrasonic inspection system to detect defects in tire casings prior to retreading. The emphasis on inspection prior to retreading is due to the fact that tires could be inspected at field level prior to shipment to a depot and hence successful application of ultrasonic inspection at this time will have the greatest immediate impact on cost savings.

At Red River, approximately 125 tires were inspected. Results of this inspection showed 12 tires gave defect indications. Ultrasonic defect indications were correlated with the standard practice of detecting separations during the buffing operation. Of the twelve tires with defect indications received, two were sectioned, and confirmed. The other ten did not correlate to buffing. The following results are correlation on the sectioned tires and representative of the defects found.

Figure 4 is a A-scan recording of the ultrasonic instrument oscilloscope cathode ray tube trace. The recording in Figure 4a shows the ultrasonic pattern from a tire section which does not contain a defect. The photograph in 4b shows the change in ultrasonic pattern which has a defect. Note the good definition between the good section and the defective section with this developed ultrasonic technique. It should be noted (although not shown in the recording) there was a noticeable dynamic time change in the ultrasonic signal indicating the defect started at the breaker belt and propagated into the plies.

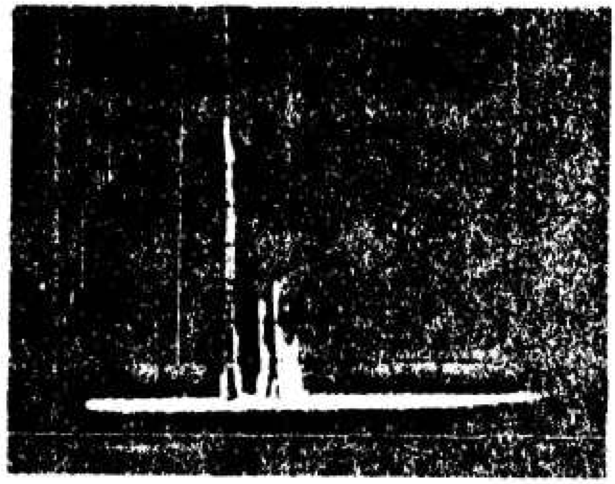


FIGURE 4a
A-SCAN RECORDING OF A TIRE SECTION WHICH DOES NOT CONTAIN A DEFECT

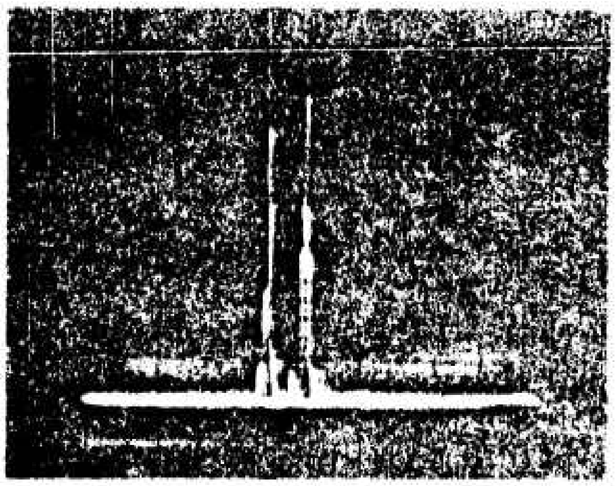


FIGURE 4b
A-SCAN RECORDING OF A TIRE SECTION WITH A DEFECT

FIGURE 4
A-SCAN RECORDINGS OF TIRE SECTIONS

Figure 5 is a photograph of this defect. The defect is a break about 3/8" deep. It extends through the outer breaker belts and into the first outer ply layer. Notice the intracord spread at the outer ply boundry which aids in defect detection. This type of defect would obviously not have been found during the buffing operation.

An example of the type of defect detected ultrasonically and confirmed by buffing is shown in Figure 6. It is a typical tread/ply separation in the shoulder of the tire.

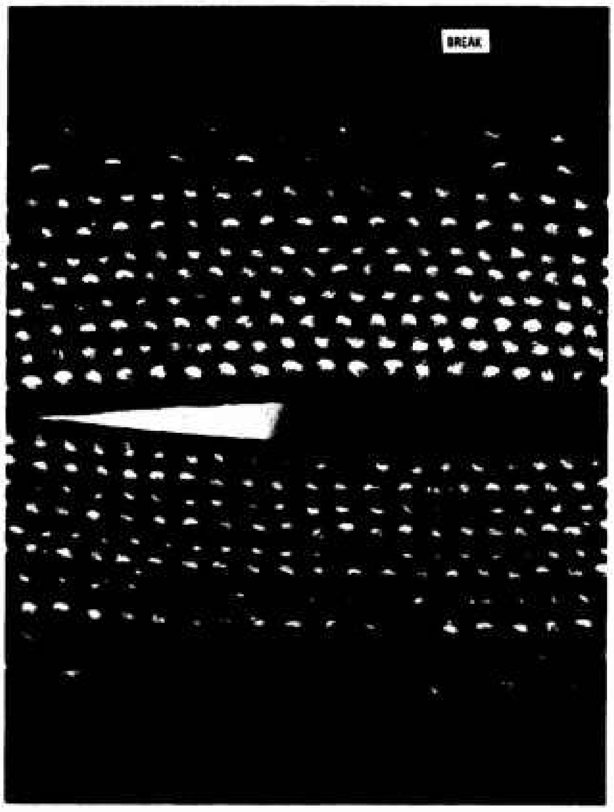


FIGURE 5
CROSS SECTION OF A BREAK DETECTED IN THE PLY OF A TIRE

ADDITIONAL TESTING

Prior to field multiple unit implementation, it was felt further testing should be performed to determine whether the system inspection parameters had been adequately optimized for this particular application. Thus, in order to provide statistical data on the type, number and location of detectable flaws in tires, a tire testing program has been initiated.

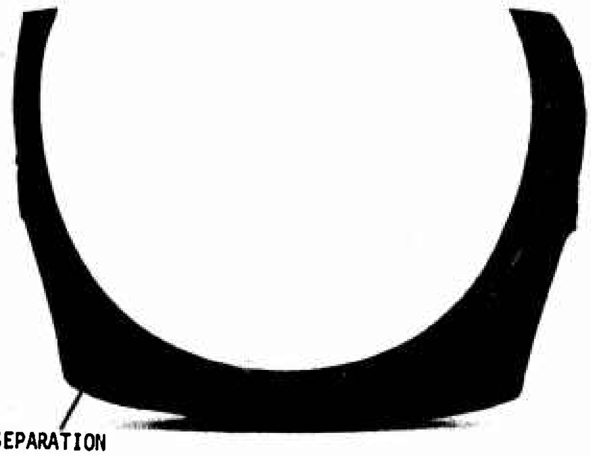


FIGURE 6
PHOTOGRAPHS OF A TYPICAL TREAD/PLY SEPARATION

At the start, 500 retread candidate truck tires were visually inspected at GARD by a Red River Inspector (in accordance with TM9-2610-200-34 Pneumatic Tires and Inner Tuber) and given a repair classification, so subsequent ultrasonic data will be relatable to current inspection procedures. Typical classifications are: Tires requiring repair or rebuild at a depot tire repair shop, or tires not economically repairable. The candidate tires are being ultrasonically inspected in the five most critical areas (center, shoulders, and sidewalls). Data on the number of tires with ultrasonically detectable defects versus number of visually rejectable tires versus number of visually acceptable tires is being generated. Flaw locations are being recorded. Tires which have flaws in each of the five areas inspected will be cut to try and establish a trend regarding defect type versus location.

The A-scan ultrasonic traces and simultaneous oscilloscope measurements, made while viewing defect signal indications are being recorded photgraphically. The tires will then be cut in the defective areas. Correlation of system indications versus types of defects seen visually will be made. The results of this phase will show whether the ultrasonic inspection can discriminate between various types of tire defects or whether only an indication of the presence of an anomally can be provided.

Results of the testing program are expected to be given orally at the Second Symposium on Nondestructive Testing of Tires.

The following is an added summary of the oral data presentation given at the Conference.

The next chart summarizes the results of the ultrasonic inspection of 450 tires. Comparison of ultrasonic test results with optical examination and physical test data confirmed that six percent of the tires had localized defects and forty-six percent had circumferential defect indications.

One percent of the localized defects observed consisted of inclusions or breaks. Five percent consisted of either cord or ply separations. Sixteen tires which presented localized ultrasonic defect indications were sectioned and examined. Visual confirmation was obtained for each of the ultrasonic indications.

Forty-six percent of the tires inspected had circumferential defect indications. Twenty-four percent of the circumferential defects were found to be associated with low tread bond, ten percent were cord separations or outer ply deterioration, and twelve percent were loose cords.

Twenty tires exhibiting circumferential ultrasonic inspection indications were sectioned, visually examined, and subjected to peel test.

The correlation of mechanical and visual test results with ultrasonic inspection data has demonstrated three significant items:

1. Localized defect occurrence is small,
2. Circumferential defects are significant in number, and
3. Ultrasonics can find both.

The first item indicates that the prime retread truck tire emphasis heretofore placed upon the detection of localized tire defects may not be most important.

The second item implies that ultrasonic inspection data obtained by scanning for circumferential effects might better indicate tire carcass quality. De-emphasis of localized

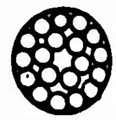
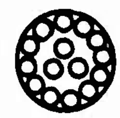
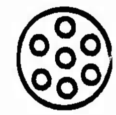
INSPECTION RESULTS

INSPECTION	INDICATION OCCURRENCE	DEFECT	DEFECT OCCURENCE
LOCALIZED	< 6%	INCLUSION BREAK	< 1%
		CORD SEPARATION PLY SEPARATION	5%
CIRCUMFERENTIAL	46%	LOW TREAD BOND	24%
		CORD SEPARATION OUTER PLY DETERIORATION	10%
		LOOSE CORD	12%

defect detection could greatly simplify retread inspection equipment and its cost.

Further, an analysis of the ultrasonic signals, microscope observations, and correlated peel test properties indicates that a relationship may exist between reflected ultrasonic signals from tire plies and carcass degradation. See the last chart.

CASING DEGRADATION INDICATION

CORD/RUBBER MODEL			
CORD/RUBBER CONDITION	NORMAL	LOOSE CORD	CORD SEPARATION
ULTRASONIC SIGNAL (IDEALIZED)			
ULTRASONIC CLASSIFICATION	NORMAL	LOW	HI
PEEL STRENGTH	100%	90%	65%

Visual observation has shown that: "normal" ultrasonic reflection signals from ply layers are associated with strong interply adhesion and tight cords, "low" reflectance signal has been correlated with loosening (unraveling) of individual cords, and "high" reflectance condition has been associated with separation of the cords from the surrounding matrix rubber. The three columns relate to our schematic model of tire degradation.

Peel tests were conducted to see if ultrasonic reflections from tire cords could show reduced strength and thus, could be related to tire degradation. It is seen on the bottom of the slide that there is a correlation between average peel strength and different ultrasonic reflections.

In summary, the results obtained from this effort show the detection of both localized and circumferential type defect conditions by means of pulse-echo ultrasonic inspection. Actual defect incidence seems to emphasize the detection of circumferential defect conditions over detection of localized defects as a measure of tire carcass integrity.

In retrospect, the fact that pulse-echo ultrasonic inspection could find carcass degradation might be obvious if one considers "best" vs. "worst" case: the pulse-echo reflected signal from "normal" plies should be different from the reflected signal from outer ply degradation, cord separation or porous bond because of the resultant impedance mismatch in the tire. The peel strength data will obviously be different. Specific correlation of ultrasonic, visual, and mechanical data has shown this to be true.

The Army has indicated interest in pursuing ultrasonic reflectance as a carcass measurement tool. Currently, work is underway to perform dynamometer and road tests for further test verification. It is necessary to see how many miles and how much useage makes a tire carcass move through the three ultrasonic classifications.

QUESTIONS AND ANSWERS

Q: What do you feel is the smallest unbond that you can detect with this system?

A: Well we have detected separations of 1/2 by 1/2, I don't know what the smallest one would be. These were separations we detected and essentially verified there. We should be able to go somewhat less than that.

Q: One of your first slides there you showed a cut that went into the core. Was that a break?

A: Yes, that was a break.

Q: Was that detected by your pulse echo?

A: Yes that was detected by pulse echo.

Q: And that's more than a 1/2 inch?

A: Yes that was 3/8 by a 1/2, I think, and interply conditions.

Q: Did I understand correctly, you use it after the tire is buffed?

A: No we used it before the tire was buffed.

Q: During testing of tires like the cross bar type, when your transducer comes across it and then its between lugs, doesn't that mess up your reading?

A: Right. In our 500 tire tests we were doing more pattern recognition. We didn't have automatic set force scan inspector, we watched the A scope as you do for separations, you do get enough noise that larger separations were detected underneath a lug.

Q: For best results how close do you want your transducer to stay to the top surface?

A: We find while working at one Mkg, we find that we like to operate at least 5 1/2" away. This is because you want to be out of the near field which is something in the order of 4 to 4 1/2".

Q: In the test work that you've done, on a large tire, what would you estimate is you time per tire in making your analysis?

A: Right now we operate about 20 minutes per tire but we are shooting for 3 minutes per tire for the final prototype system.

Q: Have you found a 100% corrolation defects in cutting the tires?

A: So far in the tires we've cut, yes. Right now as I say we were looking for the type and location of the defects, that's the next phase that we want to look at. Propagation of defects. The circumferential. We have the 2 extremes.

Q: Are you debubbling or rotating the tire?

A: We rotate the tire possibly 3 times before we make our measurements right now. We don't have to debubble when we are looking at new tires. We did look at some road tires in the 1120 and we had no problem with those. We are not looking at the passenger tire just truck tires. We had no problem there.

Q: Don't you feel that you can detect separations smaller than 1/4 by 3/8?

A: Well, yes, obviously we feel we can. Of course, what you are looking at is the circumferential type defect and the interface which goes right around the tire shoulder and so you present to the ultrasound transducer or ultrasonic beam an area that's bigger.

Q: Is the device you show used at Red River daily?

A: No the device was brought back. It was there for 7 months. Then we brought it back to our lab in Chicago and are running 500 tire test presently.

Q: Are these all bias tires, bias belt or steel belted tires?

A: No these tires are all retread candidates and are typically pretty old tires. They go from 1952 to roughly 1962 or 63. So we really didn't pay attention to type of tire. We took certain data, the mfg, the type of ply material it was, the size, all that. With the different tire considerations you have like I say on our 500 tire test to date we looked at 17 different manufacturers of tires and out of that we looked at I don't know how many different styles that they made in that 10, 15, 20 year period. So you have many in the retread candidate situation so you have a large number available to look at.

Q: Is there a plan to retread some or all of these tires and then to follow their road life in the future?

A: You mean the 500 tires that we have now? Yes. No, not on the 500 tires they will go back for retreading and hopefully will follow them through with the help of TACOM. Dave might talk a little more on road tests. The tires we got out of just ordinary road test tires are candidate for retreading at Red River.

BACKGROUND AND PRACTICAL APPLICATION OF NONDESTRUCTIVE TESTING OF AIRCRAFT TYRES IN AUSTRALIA

Peter B. Simpson – Managing Director
Automation Industries Pty. Limited
Rydalmere – New South Wales
Australia

INTRODUCTION

For the past two years the Inspection Services Division of Automation Industries Pty. Limited, the Australian subsidiary of Automation Industries, Inc., has performed contract nondestructive testing of aircraft tyres for the two major internal Australian airlines, utilizing air coupled ultrasonic test equipment wholly developed by our company in Australia.

This paper will look at the background of the development of this test equipment and, possibly more important, at the statistical and economic results obtained by the practical implementation of this test method.

Since the inception of our service two years ago and after the airline fleet tyres had all been tested, both domestic airlines have reported no thrown rubber from tyres that we have tested. The results speak for themselves and indicate that the equipment and service that we provide is not just another 'potential test' but a proven and very economical method for evaluating ply separation throughout the service life of the tyre.

NEED AND DEVELOPMENT

The original need that involved us in tyre testing in Australia was a request from one of our internal airlines to assist them with their tyre problems. They were experiencing great difficulty with thrown tread rubber, particularly with DC 9 aircraft where the possibility of ingestion of thrown rubber into the engine exists. This problem was highlighted by the occurrence of thrown rubber into a DC 9 engine causing a dramatic forced landing and, at this time, the Department of Civil Aviation were going to bring down very tight restrictions on the retreading of aircraft tyres, particularly with DC 9 tyres. The airlines were convinced that the main problem was not due to tread un-bond as a result of retreading but to ply separations which the retreader was unable to detect prior to retreading using such current methods as air injection. The need was, therefore, to devise an economic test system which would locate ply separations at the pre-retreading stage.

Based on some work that had been done by Automation Industries in the United States, we reviewed their results and took a slightly different instrument approach although we used the same concepts, i.e. air-coupled, low-frequency ultrasonics. Our method of attack was to embark on a programme of developing equipment and testing tyres whilst we continually performed destructive correlations. In this period, which lasted about six to nine months, we learnt to overcome such basic problems as tyre profile, varying rubber thicknesses and various tyre sizes. We also determined many electronic and mechanical requirements which had to be overcome to maintain repeatability.

At the end of the first twelve-month period, we had developed our MK I TYRESCAN unit which was able to test aircraft tyres and, apparently, reliably locate separations in excess of ½" diameter. However, many false indications were obtained, still due to mechanical and electronic problems, together with operator interpretation. However, it appeared that the system was fail-safe as it was apparent from extensive destructive tests that we were not missing any separations in excess of 1" diameter and it was decided to implement the system on a six-months trial basis testing all the tyres from one airline.

The results were encouraging in that no thrown rubber was reported in this trial period and it was becoming obvious that we had a winner. The next step was to improve the test results by eliminating false indications.

Further research and investigation was pursued, concurrent with field testing and, after a further six months, a MK II instrument package and mechanical handling gear were put into operation. This dramatically reduced the false indications and, at this stage, both Australian airlines started testing their tyres prior to retreading. At this stage,

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a test specification was developed in conjunction with ourselves and the airlines and this was accepted by the Department of Civil Aviation.

The MK II system has now been in operation for two and a half years and has tested in excess of 15,000 aircraft tyres in that time. It is interesting to note that, in that period, no rubber has been thrown from any tested aircraft tyre due to ply separation, although some rubber has been thrown due to retreading un-bond.

TEST EQUIPMENT AND TEST METHOD

I do not think it is necessary to go into any great technical depth regarding the equipment as I prefer to keep this talk result-oriented. Furthermore, the basic test method was discussed at last year's Symposium.

Basically, the unit is air-coupled ultrasonics with one central transmitter and six receiver channels, each channel separately controlled for both testing and electronic gateing. There are, of course, many obvious advantages in using air-coupling instead of water-coupling and, once again, I do not think it necessary to expand on this method. The concept of the current test is to use the equipment for mass scanning on a go/no-go basis, allowing further investigation of suspect areas to take place at a later date. The unit, as it now stands, is still somewhat operator dependent and requires a person of technician status to set it up.

Tyres are tested after removal from the aircraft and after visual inspection has taken place. No preparation of the tyre is required. Tyres are tested in a general workshop area (except for insulated panelling) and each pass of the tyre takes approximately 45 seconds (it takes 3-4 minutes for each tyre to be tested, due to handling, in that the tyre must be taken out of the rig and rotated and re-tested on the other side). Speed is not a requirement at this stage but the handling gear could be modified for the entire test to be performed in two continuous passes, using two banks of receivers. Tyres with complete separation are rejected, those showing a drop in signal are marked accordingly and sometimes buffed and re-tested and, if satisfactory, repaired and retreaded. The tyre size range that we are testing varies from small nose-wheel to 50" x 20" tyres and the changeover time for a different tyre size is approximately 5 minutes. Sidewall testing of tyres can be done as an additional test on those tyres which are known to be subject to sidewall defects.

We are reliably and repeatedly detecting ply separations and we are also able to detect loose balance patches, repaired cuts that have been incorrectly repaired and rubber degradation.

Rubber degradation is a sidelight of our investigations and we are further developing test concepts in this area. Using high sensitivity and an analogue output, we are actually able to locate the air-gaps around the individual fibres indicating the very start of a ply separation.

RESULTS

Of all the tyres tested, approximately 1½% are totally rejected for ply separation. However, this includes re-tested tyres and, looking at individual tyres as a function of their life, some 12% of all tyres that go into service generate some form of ply separation prior to the end of their projected life period. Looking further at individual tyres, we find that between 40% and 50% of all DC 9 main tyres (42" x 15") generate a ply separation up to the fourth retread stage.

As a result of our tests, both airlines have been able to increase the life of their DC 9 tyres to four retreads (previously three retreads) and 727 tyres to eight or nine retreads (previously seven retreads). This increased life of some tyres is balanced out by some tyres that are rejected at the first, second and third, etc., retread stages. Of course, these tyres that are being rejected early are those that were previously causing the damage anyhow.

Recently a low pressure DC 9 tyre introduced in 1973 of Australian design and manufacture, was indicating a heavy reject rate at the first retread stage. By analysing the test results, the manufacturer was able to isolate the location and type of defect and change his mould design to overcome this problem.

In the last six-month period, several retreaded tyres have thrown tread rubber and the airlines are now considering the testing of tyres both before and after retreading until such time as the retreading problem can be isolated and cured.

ECONOMICS

When performed as a service operation by our company, it is costing about $6 per tyre to test, but this could be reduced with a greater demand as our current system is only working at one half of its rated capacity.

Apart from extended tyre life (balanced by earlier rejects), the major savings to the airlines have been the lack of fuselage and engine damage and no lost down-time of their aircraft. Possibly the most important but intangible saving is the significant reduction in the possibility of loss of aircraft and human life.

THE FUTURE

Up until now we have provided a service and perfected the test method in practical operation. We have now developed a MK III electronic and handling gear package which will be available early in 1975 for purchase by airline operators or retreaders. This unit is designed specifically for aircraft tyre inspection.

Research and development using a MK III prototype has opened up exciting new areas of testing of truck and automobile tyres by air-coupled ultrasonics and maybe next year we will be able to report our further results in this area.

TIRE INSPECTION WITH THRU-TRANSMISSION LOW FREQUENCY AIR/WATER COUPLED ULTRASOUND

Walter F. Wulf
Mobility Systems Laboratory
US Army Tank-Automotive Command
Warren, Michigan

This paper is associated with Mr. Van Valkenburg's on the Sondicator. He has covered the technical aspects of the system. I therefore will confine my presentation primarily to its application and test results.

At the request of our Maintenance Directorate, representatives of the Mobility Systems Laboratory at TACOM investigated various methods of non-destructively inspecting Military tires for separations and other flaws that possibly could cause premature failures in recapped tires. The inspection system is needed not only to check all recap candidates, but to provide quality control on the recapping process.

OBJECTIVES

(1) Equipment Cost - $10,000 or Less

(2) Semi-Skilled Operator

(3) Inspection Per Tire - $3.00 or Less

FIGURE 1
PROGRAM OBJECTIVES

Figure 1 – Our objectives are (1) Establish an inspection system costing less than $10,000 – This would permit placement of test instruments in a large number of field maintenance stations to eliminate shipping rejectable tires to the recap centers, (2) the system should be simple enough to permit operation by semi-skilled personnel, and (3) the inspection cost per tire should not exceed $3.00.

After investigating all the NDT methods available, it was concluded that Low Frequency Thru-Transmission Ultrasound had the greatest possibility of meeting the objectives. Therefore in November of 1973, a contract was issued to Automation Industries to determine feasibility of applying the Sondicator on Military tires having a variety of tread and lug configurations. As you have heard from Mr. Van Valkenburg, the results were quite successful.

After receiving our Sondicator and completing construction of the tire holding fixture, it was June of this year before we actually started the program. Due to a heavy work load since then, we have not quite finished the study. On the basis of tests conducted so far however, we are very optimistic about the final results. More on results later.

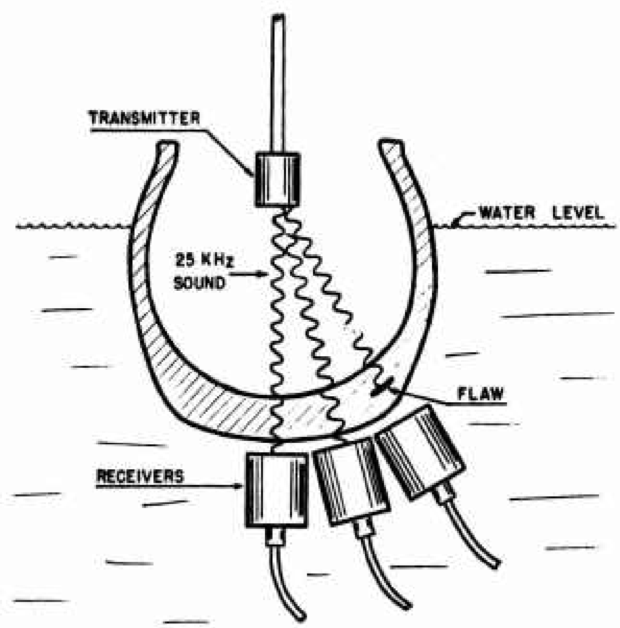

FIGURE 2
INSPECTION PRINCIPLE USING THREE RECEIVING 400 KHz TRANSDUCERS

Figure 2 – Briefly reviewing the inspection principle, this illustration shows the transducer arrangement in relation to

the tire. The 25 KHz transmitter is placed inside the tire at a distance from the receivers adequate to cover them. A minimum of four inches is required for three receivers, and eight inches for six. If space limitations presents a problem, two transmitters can be employed as illustrated in Figure 3.

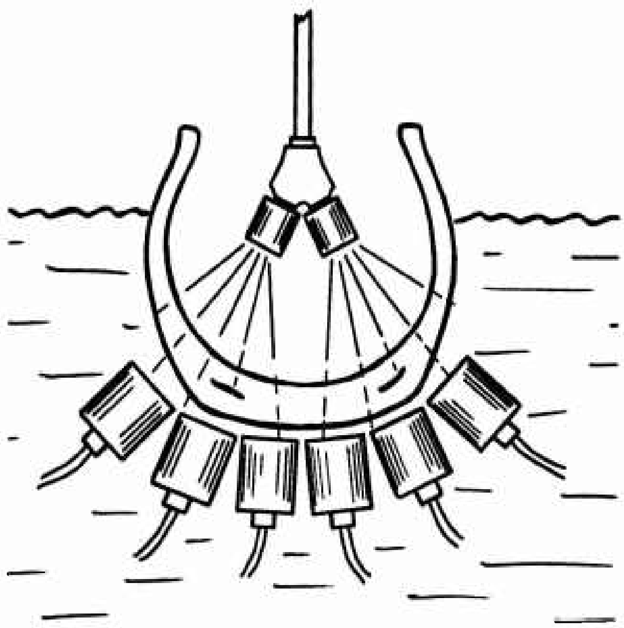

FIGURE 3
TRANSDUCER ARRANGEMENT USING TWO TRANSMITTERS AND SIX RECEIVERS

The Sondicator provides a signal strength adequate to drive six transmitters, so if necessary three could be employed. The receivers are standard untuned 400 KHz emersion type with a one inch active surface. They have a band width adequate to receive the 25 KHz signal. Since only about 1% of the incident energy enters the tire, it is easily attenuated by any internal flaw containing air or porous material.

Figure 4 – This is an overall view of the breadboard inspection system. The Sondicator is on top of the table on the left. Below that are two D.C. power supplies, one for the tire rotator and the other for the Chart Marker. These can be much simpler units, or may not be required at all depending on the type of drive and recording system used.

Looking close you can see most of the arm assembly that holds the transmitter. Its cable is fed through the small pipe which rides on a bearing up front and is held in place by a clamp near the drive pulley. The receivers are mounted on a template setting inside the water tank. They will be shown later.

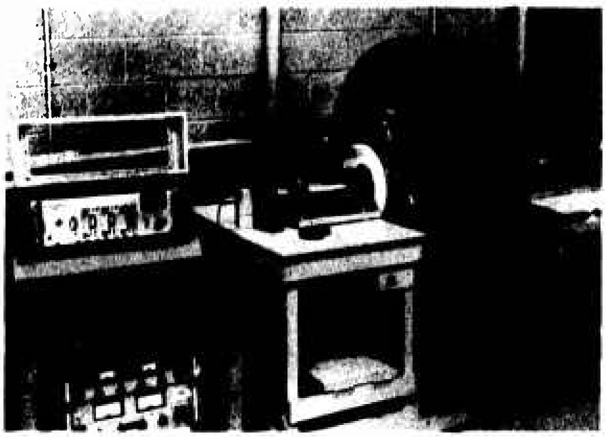

FIGURE 4
PHOTOGRAPH OF BREADBOARD TEST SYSTEM

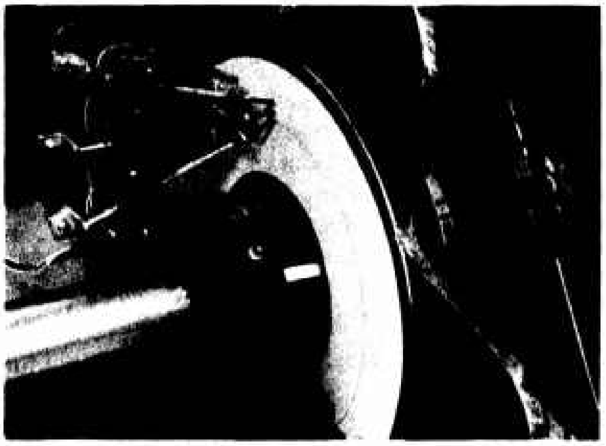

FIGURE 5
CLOSEUP OF CHART MARKING SYSTEM

Figure 5 – This is a close up view of the recording system. The circular chart, which will be described later, is attached to the rotational part of the fixture. The Chart Marker is a simple home made device employing three solnoids which are activated by relays on the Sondicator as flaw indicators appear. The appropriate solnoid then places a mark on the chart in the exact relationship to the flaw location in the tire. A conventional strip chart recorder can be used, we choose this method for the study because it is directly synchronized with the tire regardless of rotational speed or direction of rotation.

Figure 6 – This is a closer view of the tire holding fixture. It's not very fancy, but functional. We couldn't find anything commercially available that could be easily modified to mount the transmitter inside the tire. The design was kept simple so users can construct their own from drawings furnished them. The tire holding arms are adjustable to

accept rim sizes from 15 to 20 inches. Presently they are adjusted manually. We are planning however on changing them to a semi-automatic system for production application. The right side of the fixture is also adjustable by a worm screw to facilitate spreading the tire.

FIGURE 6
PHOTOGRAPH OF TIRE HOLDING FIXTURE

FIGURE 7
CLOSEUP OF RECEIVER MOUNTING METHOD

Figure 7 – This is a close-up of the receiving transducers. They are mounted on small clamps which permits securing them in any position of the template desired.

Figure 8 – Having mounted the tire and positioned the transducers, the Sondicator is now ready for calibration. This is an actual scope image showing the Wave form of sound energy after passing through the tire. The signal amplitude is adjusted first to approximately full scope height as shown. The alarm level line is then adjusted to a specified distance below the gated cycle, which in our case is the recommended 5 cycle. This is the most critical operation of all because the test sensitivity is determined by this distance.

Whenever the sound energy is attenuated by a flaw, the signal amplitude decreases. If it drops below the alarm level line a panel light comes on and the relay controlling the flaw marker is energized.

After calibrating each channel, the tire is then ready to inspect. Total inspection time per tire of course will vary depending on size. Presently it takes an average of 20 minutes for a 9:00 X 20 size. This could be trimmed considerably with a semi-automatic tire holding system, a 6 channel Sondicator, and the application of a few production techniques. As for flaw detection capability, the instrument has sufficient sensitivity to reveal a 3/8" diameter separation having a two mil air gap. The initial tests were conducted on a new tire with a variety of artificial separations cut into the tread lugs.

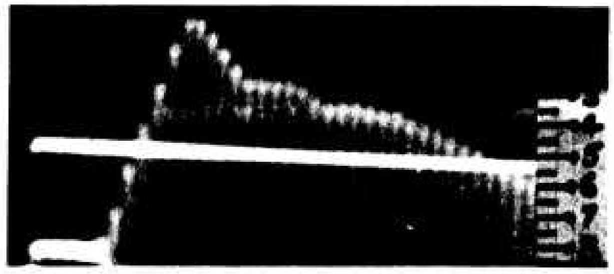

FIGURE 8
SCOPE IMAGE OF TRANSMITTED SOUND ENERGY
AFTER PASSING THROUGH THE TIRE

PRELIMINARY RESULTS						
SEPARATION		SENSITIVITY				
DIA	GAP	3/16"	1/4"	5/16"	3/8"	7/16"
3/8"	.002"	X				
3/8"	.005"	X				
1/2"	.002"	X	X	X		
1/2"	.005"	X	X	X	X	
5/8"	.005"	X	X	X	X	X
3/4"	.010"	X	X	X	X	X

FIGURE 9
PRELIMINARY TEST RESULTS WITH
INDUCED SEPARATIONS

Figure 9 – This chart shows the preliminary test results. On the left are listed the various size separations cut into the lugs. The fractional dimensions listed on top are the various distances the alarm level line was set below the

peak of the 5th cycle. The X represents capability to detect the size of separation listed. As you see, the instruments flaw detection capability decreases as the distance between the two reference points increases. For example, at a sensitivity setting of 3/16", a 3/8 diameter separation with a two mil air gap is detectable. Whereas with a 7/16 inch setting the smallest size revealed was 5/8" diameter with a 5 mil air gap.

We started with a 3/16 inch sensitivity setting because the normal pulse height fluxation, caused by the lug pattern on a new tire, is approximately 1/8 inch. This could be minimized or eliminated by increasing the water density.

Unfortunately, we only had time to evaluate 5 used tires, 4 bias ply and 1 steel belted. The 4 bias ply contained separations confirmed by holography. In general, the ultrasonic results compares favorably with holography. There are a few differences which we plan to investigate further, and will finally cut the tires up to correlate results. The steel belted tire presented no inspection problems. Only a slight increase in signal strength was necessary to receive an adequate scope image.

Figure 10 – This is the chart recording of test results on one of the bias ply tires. The chart is marked in four 90° quadrants with the 0° point starting at the tire serial number. The heavier center circle represents the center of the tread. Six scan paths correlated with the appropriate receiving transducers, are provided on each side. Flaw indications are the heavy dashes. Holography reported 23 separations in this tire, and Ultrasonics shows 29 indications. The correlation was a little closer on the other 3 tires.

As I stated earlier, we feel this system has a future. However before submitting it for field testing, we plan to proof test it with a much larger number of tires.

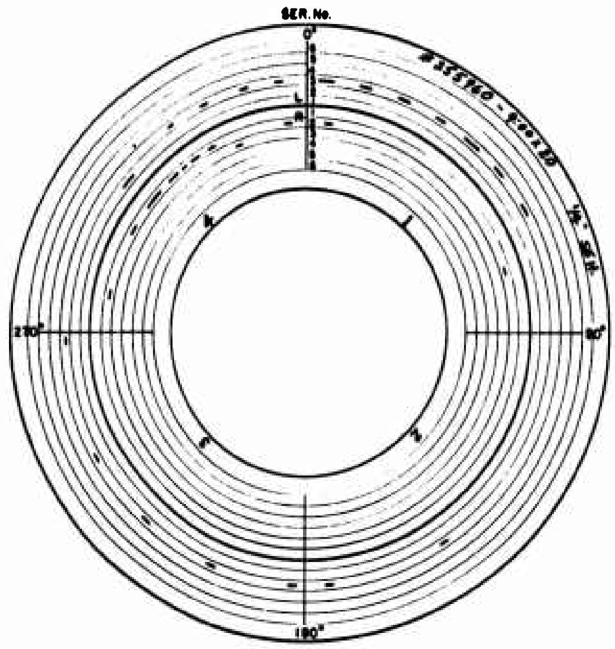

FIGURE 10
CHART RECORDING OF TEST RESULTS

CHAPTER VIII – WORKING GROUP REPORTS

WORKING GROUP REPORTS

Charles P. Merhib, Moderator

ULTRASONIC WORKING GROUP REPORT

Gwynn McConnel, Chairman

The ultrasonic working group met for nearly three hours. We had 20 tire and ndt inspection specialists in attendance. The meeting really permitted an excellent exchange of much detailed information. I am sure the attendees felt as I do the meeting was a real highlight in the symposium.

We interrogated our friends from Australia and General American Research Division and I am glad that I was also questioned similarly because the people who do the work and generated the information are always questioned. Our special appreciation is extended to the members of these organizations.

We find that there is much interesting activity in the ultrasonic tire inspection field and many continuing programs. Hybrid type systems have evolved since our last meeting. These take some of the features from water-coupled high-frequency reflection ultrasound and combine them with the thru-transmission air-coupled system. We discussed a number of subjects at length among these I will bring to your attention. The mechanisms of carcass degradation or fatigue that is cord matrix, unbond, cracking, cord stretch, etc. The comparison of capabilities and potentials including all estimates of cost of the various proposals of tire inspection systems. Another subject covered – the experience investigators have had in their equipment response to man-made and natural separations. This looks like an area where we have to really realize the difference between the response of the equipment to these types of flaws and we discussed the on-going and planned programs and objectives of various organizations. We spent some time on tire development and quality assurance applications of ultrasound and we talked about tire industry needs and these include chemical, mechanical degradation and application and quantitative grading, tire development in quality assurance applications in particular gaging, belt edge and ply separation detection, tire road test application to reduce testing time and accurately predict tire performance, additional separation and degradation correlation with failures.

In summary or conclusion, I will practically read what I said at the last symposium that all of us who did participate here express our very sincere appreciation to Paul Vogel for taking the initiative and conducting an excellent symposium.

HOLOGRAPHIC WORKING GROUP REPORT

Ralph Grant, Chairman

Good morning Gentlemen.

We stand on record for being able to finish in the shortest period of time. When I then began to go over my notes, I reviewed the bewildering amount of suggestions made by that small body. I felt very much like that story of a very mighty eastern ruler many years ago who on his 21st birthday was given a harem of 21 women. He looked rather bewildered in the beginning said it wasn't so much a matter that he didn't know what to do; he just didn't know where to begin.

Our first recommendation goes back to a comment that Paul Vogel made in that we have a strong feeling and, I might express it in just a little different way, a little bit of alarm in some of us that the attendance at this meeting is as low as it is. We in some way rationalize that in a sense probably due to the economic conditions budgets as they are that many fewer people could attend the symposium.

As a result, Firestone has made the suggestion, as Paul has already referred to, that our next meeting take place in Akron. The committee has strongly suggested to me that I make a few comments on that with some justification – that we feel many more people would attend the Nondestructive Tire Testing Symposium if it were held in Akron. Since most of us are affliated in some way or another with the tire industry, it usually makes it more easier to justify the travel as all of us go to Mecca one time or another and quite often can combine it with other business. As such many more could justify the travel to the symposium, and secondly, and possibly more importantly, there is such a variety of hosts and experts of people there who would attend. While here we are seeing, for example, some of the rubber companies with only one representative and some with no representatives here; almost no expression of interest and yet we know that those of us who are actively involved in the field that there is a great interest and such I think that in Akron many such people would come to the conference.

Next, we would like to see more encouragement to international people, such as Peter Simpson from Australia, who added a delightful touch to our symposium. I think that it would add a great deal more color if we had more international people involved. Considerable amount of nondestructive testing research is going on throughout the world and I've observed much of it in Japan and many parts of the Orient, in Europe and even in Russia and I think that many of these people will be encouraged to come and present their results which would give us a much more rounded outlook.

Finally, I think we would like to strongly advise that we encourage more so called "tire experts". There are a lot of jokes about experts but it makes me wonder when I see a symposium like this that we feel complete when we don't see the people like the Father of American Nondestructive Testing, Dr. Robert McMasters, from Ohio state. A meeting of this type without a representative from Michigan leaves something to be desired. So I think that some attention should be given to meetings being held in a place where many more people could economically attend it, participation of more international people and participation of more of the people that are actively involved in research in the field.

The second point which we would like to make is to place the theme of the next symposium or recommend that the theme of the next symposium be placed on the shoulders of the tire industry in that they provide for us in a special session, a clearer definition of what their needs are. You know a lot of us chase fairy tales around and quite often can get far removed from the practical reality of true life. Like the discussions of man-made separations in tires.

I think that these men from the industry not just the Akronites but the Air Force, the Army and the Navy; these men need to stand up in front of us and tell us what their specific needs are. Tell us why they want to see it. Why they need $100,000 of machinery to test for a tire separation on a 67 cent profit margin item and you are telling me it costs $11.42 to test it. You can imagine the attitude of these people.

In this session, representatives for the military and the tire industry that I would like them to get a bit more specific and tell us what they would like to see and why they want to see it and what they would be willing to pay for it.

The third area is a recommendation to our distinguished chairman, Paul Vogel, we would like to see the proceedings of these meetings a summary by the chairman about what is going on in NDT. A guide to the newcomer as well as an orientation to the individual who is heavily involved in these programs. I know between meetings I've had, I have become quite bewildered at times.

I think that Paul has provided a marvelous service to us but kind of putting together in summary form who is doing what and what appears to be their basic objectives. He is the type of fellow, I have noticed by the number of times my phone rings, that isn't bashful about getting some information. If we knew who was doing what and what the basic objectives were, I think it would help to provide better future guidance.

Item 4, it will be interesting to see at the beginning of the next meeting by a man such as Dr. McMasters a brief short review of the various nondestructive methods which apply to tire testing. I am sure that there are individuals and I've heard comments for different individuals as they come into the room that are kind of puzzled about the physics of one method compared to another.

We would like to see a realistic and objective review of all the methods, cost comparisons and the basic technical effectiveness compared of each method. Possibly in that same paper or more ideally by someone who is more deeply financially oriented a review of the economics of NDT. The cost effectiveness of testing. Again, one doesn't spend $10 testing a tire which has a 65 cent market value on it. So he says the hell with building a tire, I'd rather go out and do something else. I think a little bit more economic consideration would be useful to us.

Next, members of the committee have so aptly pointed out, particularly Dr. Potts of Firestone, that what we in the tire area have begun to think of as nondestructive testing of tires is an extremely limited view as compared to the overall field of nondestructive testing, which is in definition an evaluation of the materials not just looking for holes, cracks, voids and that sort of thing.

We would like to see a little more emphasis on the overall aspects of materials evaluation, for example, more work on cord strength, core degradation, we were particularly impressed with the paper of Walter Wulf. I think we need more of that sort of thing. A paper hopefully summarizing the basic quality assurance tests and procedures presently used by the rubber industry.

Next, we would like to see a closer affiliation, a little more brotherhood, with the ASTM, The American Society of Testing Materials, they head the committee on the structural integrity of tires. I would like to suggest that as a representative of our committee, Mr. Vogel invite the members of that committee to our next session, and possibly have one of them summarize their activities. Try to put forth more efforts to to combine the efforts of these two groups.

The next item refers to standards. A subject that is very close to my heart. A subject I tend to antagonize people with so I don't talk about it too much but I think something needs to be said about it. We would like to encourage more work on tire nondestructive testing standards. Very briefly, it never ceases to amaze me, people come to me at the university and ask me to qualify their test methods on new scientific procedures and what they have done in the past with the greatest sincerity is a desire to learn what they are doing so that they grab a dozen or two dozen tires and have tried to analyze them with a new piece of equipment which they aren't sure about, which may have great promise and great potential. Much could be gained, I think, by the generation of tires by someone such as NHTSA of the DOT. The establishment of a set of standards tires and standard sizes with known anomalies, known defects such that those who are developing machinery and those that are new to machinery and those that are training their personnel might use these with a clearly documented set of data as to what exactly is in there. Of course in the generation of such things a great deal and a great amount of destructive testing must be done. But such things could be accomplished and we must always question credibility in our field until such things are done.

Next, we would like to see the encouragement of additional work on the classification of anomalies in passenger, truck and aircraft tires. More information on the meaningfulness of realistic anomalies in tires.

That concludes our basic recommendations with one final thought and that is what about the future of where this group is headed. We would actually like to see some attention placed on the invitation of one or two papers on the future needs of NDT of tires. Many of us are looking at tires that were designed 20 years ago. I am very impressed with the work that the Army has been doing in ultrasonics but interested at the same time at the age of the tires that they are looking at. What about the testing of some of the new things we are going to be seeing in the next 5 years. I predict we are going to see some very exciting developments and changes from the old, basic process of putting the materials into the compound to get the bonding between the rubber and glass, the bonding between the brass and the steel. I predict in 5 years we are going to see us moving away from that; I think we are going to be seeing more of the polymer coatings.

I would like to see someone address themselves very briefly

in these various stages as to what test methods would be used to explore these types of systems. The use of the new composite materials which are now much more expensive to use in the general area of tires. We are inevitably going to see some of these materials. Some attention should be given to, rather than nondestructive testing always trailing, we've always been 20 years behind the new designs. Hopefully, being able to get out in front and evaluate some of our techniques.

That ends the basic recommendations of our committee as they have focused predominately around and about the hopes for the next few years with the hope that it becomes more viable and more meaningful to all of us.

QUESTIONS AND ANSWERS

Comment: I differ from Dr. Grant's suggestion that we try to write standards on NDT methods. I think that it is a bit premature.
Reply: I totally agree with you that it is premature but we have got to start somewhere. Right now we don't have the commonality of information to talk about it. We must have a common ground on which to stand in order to have really good progress.

INFRARED WORKING GROUP REPORT

Nicholas M. Trivisonno, Chairman

A small but dedicated band of us met to discuss the present position of infrared with regard to the nondestructive inspection of tires. Several observations and recommendations came out of the discussions we had. We still think that infrared methods may have some possible application in the routine nondestructive testing of tires. We felt that we could not adequately answer this question, "Can a highly sensitive and say computerized infrared instrument like the Monsanto system look at a tire very early in a rolling test say after 100 rotations and detect irregularities on the basis of the amount of heat being generated very early in the game. We felt that this area had not been adequately explored to date with the present equipment that is available. Unfortunately, some of the people who have had the best input in this area were not present for the working group session. We feel that one of the advantages of the infrared technique is that it does inspect the tires under dynamic load conditions which do or can closely simulate the use conditions of the tire. There is some question as to whether the road wheel really simulates the use condition of the tire adequately and completely. But the fact is that right at this point it is the best available simulation and I think with the proper experience you can make allowances for the differences between road wheel and regular road conditions. One shortcoming to the infrared method seems to be that the heat signal develops relatively slowly and this takes something on the order of a minute or two to appear on the surface of the tire where it can be detected. This, maybe, is one of the things that precludes it being used as a routine very fast method and unfortunately this, too, is one area where some of the people who have the best input were not here for the working group session.

We also felt that there hasn't been enough effort put to defining exactly what it is we should be looking for in the tire.

What is it that causes the tire to fail. Most of the effort has gone into looking for things like placement of components — that would be x-ray inspection or looking for separations as in ultrasonics. Certainly these methods are very important and a very great utility and this is very well evidenced by the fact that people are buying these instruments and using them. But we know that even a tire with perfectly placed components on a tire that has no separations can fail prematurely for a variety of reasons. Consequently, we know that tires that have fairly large separations can run very well, and if you push them hard enough they will fail somewhere else.

Now the major utility of the infrared method to date has been a sort of a semi-destructive research and development method rather than a nondestructive inspection method. Infrared has been used as a diagnostic tool for evaluating tire design parameters and materials for the effects of tire durability. Infrared methods have been very useful in detecting the initiation growth of a flaw which perhaps was not originally in the tire or not originally detectable by other means. Infrared methods allow us to stop a test before a tire has completely come apart and then this gives you a much better chance to determine why a tire has failed when it does.

So in summary, I would say that we still think that infrared methods may possibly have some capability for nondestructive inspection early in the game and that these possibilities have not to date been adequately explored. Also we think we do not know enough about the failure mechanisms in the tire and exactly what it is we should be looking for in a nondestructive inspection method. We feel that infrared techniques occupy a very unique position in that they inspect the tires under dynamic load conditions and detect heat generation defects which are not necessarily related to presently recognized flaws in tires.

X-RAY WORKING GROUP REPORT

Ted Neuhaus, Chairman

We were commenting about the number of tire manufacturers present. At the x-ray committee meeting we had 6 tire manufacturers which I think was a pretty good representation. Representatives were General, Bridgestone, Firestone, Goodyear, Mohawk and Kelly-Springfield. I might also comment having Bridgestone will also give us some international representation.

As usual the first topic of discussion in x-ray was centered around automatic imaging capability. This is a continuing subject. It is an attempt to replace the operator and also decrease the production time of inspection. But the general consensus was that we have done about as much as we can with automatic image analysis. At the present time we can accomplish automatic imaging on conditions such as turn ups, belt centering, staking, etc. It was also indicated by one of the manufacturers of x-ray equipment, Imagex, that they have already accomplished successful automatic analysis of belts. I think that we were in complete agreement with the most accurate work at this point for automatic imaging would be on the beads.

The ideal condition for automatic imaging would be air inflation, fixed rims, and a bead-to-bead x-ray tube. It was also indicated that at the present time green tires are being measured successfully for belt centerline and safety.

It appears that there is still some controversy as to how accurately we are measuring the deviations in the belt. Also we had a discussion as to what improvements the users of equipment would like to see the manufacturers include and some of these comments were as follows: Simplicity of maintenance of the x-ray systems, this would also further reduce the cost. We've heard this before. Better imaging systems with respect to sensitivity and stability was pointed out. It was also felt that an item that is small but very important is that we should include as manufactured a revolution counter on the handler. It should be an operating requirement. It was pointed out that as a result of having the revolution counter you could have an improvement in the number of tires per day by reduction of inspection rotations in other words unnecessary rotations of the tire. It is also a necessity for uniform inspection. The users also indicated that there should be a good design for a defect monitor. The best results that we've had to date are with the felt-tip replaceable felt tip marking pen, using it in different colors. This would mark the sidewall of the tire. It was also indicated that we need a penetrameter. The existing penetrameter is a step wedge with holes of various sizes. It was indicated that we don't need the holes, we need the measure of resolution on different core materials used in the tires.

Also it was indicated that if any improvements are to be made in the imaging they should be adaptable to existing x-ray systems; in other words, not necessitate the purchasing of an entire new system, to incorporate the improvement.

Now a very important point and I think an indication of success in the last year. It was generally agreed upon that there is a correlation – it has been achieved between the belt condition and life of the tire. In effect what we are saying here is we can correlate uniformity through the x-ray findings.

The general opinion is with the new MPS 119, this will dictate additional need for front tire x-ray systems. There is also a need at the present time for a combination uniformity force variation x-ray type machine.

I think a very important point was made that in many instances the tires that passed uniformity failed acceptability and this failure has been evident going back and inspecting the tire with x-ray.

I think that pretty well sums up the x-ray portion.

APPENDIX A – ATTENDANCE ROSTER

2ND NONDESTRUCTIVE TIRE TESTING SYMPOSIUM

ATLANTA, GEORGIA

SPONSORED BY
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

1-3 October 1974

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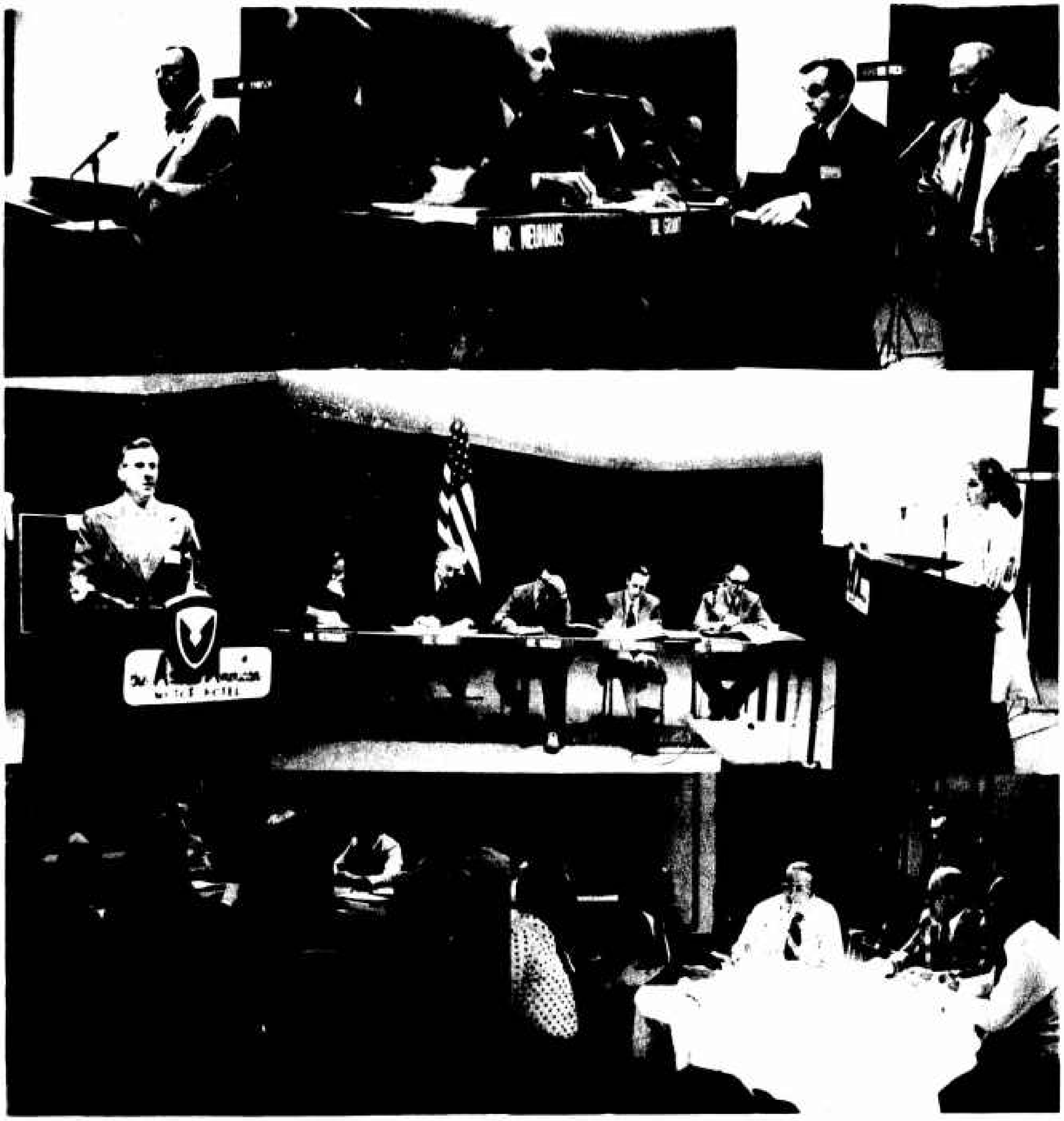
Clockwise from top right: Working groups, Mr. Beeghly, Mr. Bobo, Mrs. Berardi registering Mr. Kaplan, Mr. Darcy as banquet MC, M. Boutaine, Messrs. Darcy, Merhib, and Blanchard, center: Mrs. Vogel and Mr. McConnell



Clockwise from top right: Messrs. Pica and Vogel, Mrs. Earing, Aircraft Tire Working Group, Ultrasonics Working Group, Mr. Wulf, Mr. Johnson, Dr. Grant presenting Holography Group report, center: Working Group Chairmen

Clockwise from top right: Mr. Forney, Dr. Johnson, Mr. Shaver, Messrs. Boutaine and Vogel, Messrs. Bobo and McConnell, Mr. Simpson, Mr. VanValkenberg, Mr. Neuhaus, center: Mr. Blanchard and LTC Henry

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AMMRC SP 78-2

PROCEEDINGS OF THE THIRD SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

Sponsored by
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

PROCEEDINGS OF THE THIRD SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

Editor
PAUL E. J. VOGEL
Materials Manufacturing & Testing Technology Division
Army Materials and Mechanics Research Center

27-29 January 1976

The Holiday Inn Cascade, Akron, Ohio

Sponsored by
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

This document was published by the Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172.

PREFACE

This Proceedings follows the format of those for the 1973 and 1975 symposia. Much new material had been presented in it, however, and while it appeared for a time that the subjects under discussion had reached a plateau, it now seems that new impetus has been given to failure analysis, its accompanying tools, and to methods of correlation of reliability testing and nondestructive techniques. It has become apparent that we must turn to fleet operators, their suppliers, and their rebuilders to join with the practitioners of the various disciplines to learn the significance of particular anomalies, to learn how and if the anomaly can be related to failure mechanisms, and to develop instrumentation that can detect significant anomalies at the earliest possible stage in the life of a tire.

After more than four years of corresponding, visiting, writing, and editing, your editor senses that the nondestructive testing art is on the verge of bringing all the loose ends together into a package that will be of great value to the users and the producers. He does not have the solutions and only hopes that by asking the questions of you, the readers, that the needs, opportunities, and recommendations for concentrated effort will be explored and possibly answered - or even only enunciated for others to consider and research.

The preparation of the Third Symposium spanned two administrations of the Akron Rubber Group and it would be inadvisable to list the many fine people of the Group who assisted our effort lest someone be unintentionally omitted. The Akron Rubber Group was not a figurehead host. Their members gave outstanding support in many specific areas and our deep appreciation is expressed to them all.

Paul E. J. Vogel

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28 January 1976

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Infrared	Nicholas Trivisonno
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29 January 1976

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30 January 1976

0900 Hours	BUSES DEPART FOR GOODYEAR TOUR

CHAPTER I - WELCOME TO AKRON

G. Robert Moore
Chairman, Akron Rubber Group
Harwick Chemical Corporation
Akron, Ohio

Ladies and gentlemen, on behalf of the Akron Rubber Group and the city of Akron, I welcome you to the Third Symposium on Nondestructive Testing of Tires. As many of you know, Akron wasn't always the rubber capital of the world. As a matter of fact, several other industries have been renowned here in Akron. The milling industry started out in the early 1820's and the reaper industry was prominent here in Akron in the early 20's and 30's and then moved westward. The rubber industry was founded here in 1870 by Benjamin Franklin Goodrich. He started out in small hose and similar rubber type materials. There are other prominent names that sprang up around the end of the century, names like Diamond, Miller, Firestone, Sieberling, Goodyear, and Star. Some of these you may remember; others are still prominent here in town.

Quite naturally, then, since Akron is the rubber capital of the world, the largest assembly of rubber technology is also here, and has banded together to form what we know today as the Akron Rubber Group. Our first Group meeting was in February of 1928, and has grown consistently with the rubber industry until today we have over 2,000 members. We have followed basically the same meeting format for many years. We have three technical meetings a year: one in the fall, generally in October; one in the winter, near the end of January; and one in the spring. We also have other types of outings for our general membership. We have a family night in the fall which is a sports type of evening, where we invite the family to go to the Coliseum to a hockey or basketball game. In the winter, we have our scholarship dance. This year it's going to be held around Valentine's Day at the Firestone Country Club. During the summer, we hold what we call the "world's largest golfout" at the Firestone Country Club. All members and guests of the Akron Rubber Group are invited and usually over 600 golfers participate.

The Akron Rubber Group is also somewhat philanthropic in nature and does maintain a nonprofit posture. We sponsor five scholarship students. Each of these deserving students must maintain a 3.0 overall average in their scientific or engineering field of endeavor. In addition, we hold a technical lecture series which consists of 10 or 12 lectures throughout the year. This year we started in January and will run through to about the middle of March, holding it on a Monday evening at Knight Hall at Akron University. These lectures are generally attended by about 9,400 people, and they are very technical in nature. I would like to invite all of you to attend our Annual Winter Technical Meeting, which is this Friday. It starts at 2:00 p.m. and admission is by membership to the Akron Rubber Group. If any of you are not members of the Akron Rubber Group, the membership tickets will be available at the door. We will have two technical symposia which will run simultaneously. One will be on rubber processing and the second is on "New Flexible Elastomers for Automotive Filler Panels and Facia." This is something completely new as far as the Akron Rubber Group is concerned. I would like to encourage all of you to attend if you so desire.

If any of you are looking for something to do here in the evenings, I would recommend the concerts and the ballets at the E. J. Commerce Performing Arts Hall. Also, Akron is renowned for its restaurants, and I can recommend several.

If you have any questions, or if there's anything at all that we in the Akron Rubber Group can do for you, don't hesitate to ask. Again, I want to welcome you and thank you for having me as your guest.

OPENING REMARKS

LTC Edward E. Chick
Army Materials and Mechanics Research Center
Watertown, Massachusetts

It is a pleasure for me to be here with you this morning to participate in the Third Symposium on Nondestructive Testing of Tires. First, I'd like to thank each of you for being here, thank the authors of papers you are about to hear, and the Akron Rubber Group for the support they have given in planning this meeting. We at the Army Materials and Mechanics Research Center are very pleased to be able to participate in this symposium and we believe it appropriate that the Army as well as the Materials Research Center do this because we are a pretty sizeable customer of the tire industry. The research and development community of the Army must, therefore, be intimately involved in the tire business. We believe that the Army's research community, which contains the Army Tank/Automotive Command's laboratories as well as our own, have made valuable contributions to the overall field of nondestructive testing of tires, and we know that the NDT Information Analysis Agency at our Center has been of service to you. I have reviewed the abstracts of the papers to be presented and also the previous symposia Proceedings. I was gratified to see that there are very obvious advancements in the techniques involved with the testing of tires, including the reliability of the procuct as well as apparent reductions in the cost. Cost reduction, of course, is the name of the game and it is vital that we continue making major progress along these lines. In order to do this, of course, requires additional investment in time and resources. To save money, we have to spend money. Each of us can only hope to attain what the Army sometimes refers to as "the biggest bang for the buck."

I came to my present assignment from the Army's European Research Office where I was fortunate enough to be able to travel around and visit various university, industrial, and nonprofit research organizations, and I did have a part to play in some of the nondestructive testing activities including the International Research and Development Corporation's research efforts in their laser speckle pattern technique. So I am familiar with the work that you people are doing.

I hope that you enjoy the symposium and that it will be a rewarding professional experience for you. If there is anything either I or my staff can do for you, please let us know.

CHAPTER II - KEYNOTE ADDRESS

Richard S. Walker
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Akron, Ohio

If we look at the record, tires are better than ever and an extremely important factor in the "good life" we lead and a key to the prosperity we all desire for the future. After the discovery of the wheel itself, the invention of the pneumatic tire was a necessity to permit the development of our current most important mode of transportation, the motor vehicle. I, for one, firmly believe that automobiles, trucks, busses, and off-the-road rubber tired vehicles will continue to play their vital role in our lives for the foreseeable future. Rail, water, and air transport are also important but would soon grind to a halt without the support of road transport.

Look what has happened in just my lifetime! When I was a boy, a trip from our home in central Massachusetts, down the Connecticut Valley and along Long Island Sound, to my grandparents home in Westchester County, NY, was a major trip. Essential equipment carried in the trunk included the jack, lug wrench, and spare tire but also needed were a tube patching kit, tire changing irons, an air pump, and pressure gage and probably spare tubes. Not to mention chains, monkey links, candles, and lap robes if it was to be a winter excursion.

The roads, of course, were far inferior to those we are accustomed to today. Rough and full of pot holes. The chances of making such a trip without tire failure were slim indeed. Snow tires and snowplow equipped highway trucks had not yet become common and chains were the order of the day during snow periods. Broken chains also took their toll and caused punctures in many cases. Service stations to repair or replace tires were few and far between so the burden of keeping four good tires on the road fell on the motorist himself. The foresighted traveler had at least one, and probably more, spare tires with tubes mounted on rims and ready to go. If not, the tire had to be taken off the rim, a new tube inserted or the old tube patched and the assembly put back together followed by the exercise of pumping it back up by hand.

Today, only the jack, lug wrench, and spare tire remain. Even these are seldom used and probably they also will be obsolete as the run-flat or self-sealing tires reach maturity and reduce the normal complement of a car to four tires from the present five. As an aside, while it probably is not absolutely essential, I do recommend that the air pressure gage be retained on a vehicle and used periodically to insure proper inflation and thus maximum service of the present tires, good as they are.

At that time, we could expect five to 10,000 miles from a tire. In more recent times that value was pushed up to the 20 to 30,000 mile range and the introduction of the tubeless tire improved safety. Today we have the 40,000 mile radial tire which is also extremely durable. On a cost performance basis, allowing for inflation, tires are still a very good buy.

As an indication of relative tire values over the years, our sister magazine, Modern Tire Dealer, published a replica of a tire price book for 1920. In this listing there are basically two types of tires. Fabric reinforced and cord reinforced. The fabric tires were generally guaranteed for 5,000 miles and cost in a range from about $16.00 to as much as $50.00 or $60.00. Cord tires were generally guaranteed for 8,000 miles and prices ranged from about $30.00 up to over $100.00 in a few cases. Some of the fabric tires were rated for 7,500 miles particularly those described as Ford sizes. At least five of the cord tires were guaranteed for 10,000 miles and one manufacturer even stuck his neck out for 12,000 miles. As you can appreciate, however, at prices that don't seem out of line for today's tires they gave considerably less treadwear. And, we must remember, they required tubes which cost $3.00 to $10.00 additional when considering the total cost.

We are not here to discuss financial business particularly but these accomplishments have been made by an industry not famous for profitability. Wall Street and the investment community have consistantly rated the rubber industry below par due to low profits and below average return on investment. This does effect us as will be pointed out later.

Now! Why are we gathered here this week to discuss nondestructive testing of tires?

There are two important, major reasons why tire companies spend large sums of money for all types of testing.

The first is the most important and overriding reason for our existance. It is to provide the motoring public with the safest, longest lasting, and trouble-free tire possible consistant with

the quality level involved. This is basic and should be uppermost in our minds at all times.

We sometimes lose sight of the forest because of the trees and although our superiors' wishes and the profit of the company must be considered, the ultimate goal we must meet is for John and Jane Public to be able to go to work, shopping, school, vacation, or across country with minimal attention to their tires ... and no trouble due to construction or manufacture of those tires.

The other reason stems from the first and concerns our obviously selfish desire to avoid warranty replacements, scrap tires in production and, above all, to avoid large scale recall problems. Any of these problems are expensive and are nonproductive for both the consumer and the company. Even if the customer is satisfied that fair treatment was received in a replacement or allowance, that person has been put through an extra period of inconvenience. The company, also, loses money on the deal. All of this, of course, must be borne by the consumer in the form of higher prices.

Let's do some very elementary arithmetic. Production of automobile and motorcycle tires in 1975 (not one of our better years) will exceed 150 million units. Using 260 working days this breaks down to over 500 thousand units per day or 170 thousands units per shift in a three-shift day. Assume an average wholesale price of $25.00 per tire. On the basis of these assumptions, if just one shift of all United States tire manufacturers production were to be recalled, value of the tires alone would be over $4 million. Add to this the costs of the program and you can see we are talking about big money.

We are all aware of the tremendous amount of destructive testing carried out by tire companies. There is still no alternate, as a final test, to putting tires on a vehicle to find out how they will perform. We cannot, however, test too many production tires destructively and make money. That has created the demand for nondestructive tests which brings us together at this meeting.

The ultimate goal probably should be one or more nondestructive tests on every tire produced. This would provide the maximum assurance that every tire shipped would perform satisfactorily and keep warranty or recall returns to a minimum.

Saying this, and looking over this audience, I see the suppliers of nondestructive testing equipment gazing at the ceiling with big dollar signs dancing in their eyes like proverbial sugar plums. I'm sorry but again money, unfortunately, rears its ugly head.

As with most situations, we must compromise. The cost of nondestructive testing, or indeed all testing, must be balanced against the value obtained. Yes, warranty and recall programs cost money. It makes no sense, however, to spend even more money to reduce these programs to zero. There has to be a balance which equals the lowest net cost to the company.

We must do enough testing so that the quality assurance level (the laws of chance to we gamblers) will be of such a nature that we can be reasonably sure that tires being shipped will be primarily satisfactory thus minimizing any large warranty costs but not so much that testing costs more than any possible savings in warranty costs.

I cannot tell you where to draw the line. The specific point will vary from company to company and probably even from plant to plant within the company. This is a condition which must be analyzed carefully and determined by actual experience as time goes on.

My point is that we must keep in mind that we can provide valuable development information but the greatest gain will come from providing production people with a tool which will help to insure quality and will help spot trouble spots. We must do this, however, without adding excessive costs in the process.

If a really good job is done with nondestructive testing, furthermore, is should be possible to spot and identify troublesome situations of either a temporary or long-term nature so that these problems can be rectified with a resulting increase of productivity and quality as they are eliminated. These two, productivity and quality, are among our major goals to be met for improved profitability.

Meeting these goals would be desirable under any set of conditions but become extremely important in the face of threats by government or consumer groups forcing any real large scale recalls. As pointed out before, recalls could cost a company a great deal of money. Even the threat of a recall, however, could cause the expenditure of considerable amounts of money in legal or related costs even if the actual recall never takes place.

In spite of all best efforts, it is entirely possible that recalls will occur. In this event, nondestructive testing could be invaluable. Depending upon the reason for the recall, it is entirely possible that actually defective tires could be identified and that those which are not defective could be cleared and returned to inventory for resale thus reducing considerably the loss which the company might otherwise incur.

I don't think that it is necessarily bad for us to have the government or consumer groups looking over our shoulder and providing a stimulus for us

to do a better job. I am, however, somewhat at a loss to explain why the federal bureaucracy has singled out tires for such extreme regulation except that tires are highly visible and easily identifiable and once an item is involved in regulation large staffs and empires seem to be built by the bureaucrats. We are not perfect and as long as such monitoring is fair and not oppressive it can be a healthy condition making the public feel more secure. The safety record and the value delivered by tires today do not, in my mind, justify many of the regulative measures already in effect or being proposed.

What many of the regulators seem to forget is that we are in a very competitive industry even if it is somewhat limited in number of companies. Particularly here in Akron, if one company puts out a new line of tires it is not long before many of you here and other chemists and engineers of the competitive companies have a quality rating for that new line of tires. If it should turn out that this line is below average in the market place that fact will soon be known throughout the industry and the word gets back to the company involved. If necessary, additional design and development work gets cranked up on a crash basis as many of you present well know. This self appraisal is probably even more effective than any regulations in keeping us on our toes and insuring ever better products.

Meeting the needs of all these groups, the company, the motoring public, government regulation, and consumer organizations, however, is why we are gathered here today and why this conference is being held.

I am not an expert on nondestructive testing and I certainly am not going to try to suggest where or how any particular test might surpass another. Speakers to follow will cover the specifics in detail of holography, infrared, ultrasound, and X-ray. The working group reports on Thursday morning will undoubtedly add considerable new insight into each test method and what the benefits or drawbacks of each may be. There should be a place for each of the tests in the total scheme.

I would like, however, to make some general comments.

Those of you who are involved with the design, production, and sale of a particular piece of testing equipment are, I'm sure, firmly convinced of the superiority of your product and that it is the best on the market. This is as it should be. You owe it to yourselves and the industry, however, to present your facts, your tests and your potential as clearly and completely as possible so that a fair appraisal can be made by interested customers.

Those of you who will be involved in the evaluation and ultimate purchase of such units should keep an open mind in your deliberations to insure that you obtain for your company the best possible equipment for optimum results at the most reasonable costs.

While these suggestions may seem very elementary, I have seen so many cases where bias or personal prejudice color the decisions of an individual or department. Such decisions may or may not be in the best interests of the company for whom they work.

There is no question in my mind that, as things shake down, some companies will opt for certain tests and other companies will settle on another machine. Perhaps every company will have every type of test but this does seem somewhat unlikely in my mind. I certainly have no personal interest in any specific test and am only concerned that the equipment selected fits the needs of the company and helps to provide better tires for the future.

I wish to thank the organizers of this conference for asking me to take part and I wish you all, participants and guests, the greatest success here and in your future operations.

BANQUET ADDRESS

James C. Gilkey
Office of Standards Enforcement
National Highway Traffic Safety Administration
Washington, D.C.

It is indeed a pleasure for me to be with you today and participate in this Third Symposium on Nondestructive Testing of Tires. I would like to thank the sponsors of this symposium for their invitation.

As Mr. Vogel has indicated, I am with the National Highway Traffic Safety Administration, of the Department of Transportation. More specifically, I am in the Office of Standards Enforcement within the Motor Vehicle Programs area. It is the responsibility of our Office to enforce the Federal Motor Vehicle Safety Standards (FMVSS). We accomplish this mission by means of an in-depth physical test program and a comprehensive review of manufacturers' certification data. This evening I will be emphasizing the physical test program as I believe that will be of the most interest to you.

I will give you a general description of our overall test program and then describe in detail one of our most interesting individual programs. Time does not permit me to go into detail on all of our programs.

The subject which I will be discussing, compliance testing, may seem at first glance to be the exact opposite of the nondestructive type of testing which you have been and will be discussing. However, I believe that there is a definite tie-in of the two types of testing, even recognizing the primarily destructive nature of most existing compliance test methods. There is always the potential that some of our tests in the future may utilize nondestructive techniques either in lieu of or as an adjunct to present methods. As an example, the new ultrasonic testing procedure recently developed by DOT's Transportation Systems Center in Cambridge, Massachusetts, might well be used to pre-screen tires for indications of non-compliance with FMVSS No. 117, "Retreaded Pneumatic Tires - Passenger Cars." We presently check for compliance with the casing requirements of that Standard by peeling back the tread and making a visual examination of the cap-carcass interface. By using some type of nondestructive pre-screening technique, we might be better able to pin-point possible problem areas and thus be more efficient in our enforcement effort.

The basic approach used in our compliance test program is to selectively sample, on a random basis, new vehicles and items of motor vehicle equipment from the market place and subject them to the tests specified in the standards. The tests are conducted at independent laboratories around the country. The number of laboratories used ranged from eight in the early days of our enforcement program to a high of 22 in Fiscal Year 1971. There were 17 in our most recent program, FY 1975. All known organizations having the capability to conduct each particular type of test are given the opportunity to bid and contracts are awarded on a competitive basis.

The high quality of work and degree of professional excellence that is present in the independent laboratories, and I am sure that many of you are associated with such organizations, is essential to a viable enforcement program. As you can recognize, it is imperative that tests be conducted strictly in accordance with the standards to ensure the validity of any failures which may occur. The effectiveness of our past enforcement efforts has been due, in no small measure, to the high caliber of work in the independent test laboratories.

We assign contract technical managers for each individual standard enforcement program. It is their responsibility to monitor the testing program by making periodic visits to the laboratory to ensure that correct procedures are followed and by reviewing all test results for accuracy. As further insurance against invalid results, we have an internal OSE Laboratory Audit Program. One of our engineers, who is highly skilled in instrumentation and calibration techniques, makes periodic reviews of the laboratory operating and calibration procedures. This engineer, who reports directly to the Director, OSE, helps to ensure that procedures and equipment are within prescribed guidelines.

If a failure occurs in our laboratory test we then initiate a comprehensive investigation on the item which failed. One of our first actions is to notify the manufacturer by phone of the failure. This permits him to immediately swing into action to check the adequacy of his product. We then follow up with a more formal document which we call the certification information request (CIR) letter, which may ask many questions but, most important, it requests the manufacturer's certification and surveillance test data. Parallel to this action we may conduct retests on the item and review other relevant data on the subject. After all of the information has been collected, our engineers conduct an intensive analysis of

the data. We are particularly interested in the testing which the manufacturer has conducted both for original certification of the product and for in-process quality control. We review the procedures and equipment used as well as the results obtained. If there are differences in their results as compared to ours, we attempt to ascertain the reasons for such differences.

After completion of the analysis, we usually hold an informal technical meeting with representatives of the manufacturer and discuss any issues which are still unresolved. One of the primary considerations at such meetings is any recall action which the manufacturer may be considering. After the meeting, a decision is made, based on the technical data, as to whether there is a strong indication of noncompliance to the standard. If so, the case is forwarded to our Office of Chief Counsel for appropriate legal action. If not, the case is dropped.

The process which I have just described is the most simplified case. In many instances, there are several iterations of certain portions of the process. For example, there could be numerous letters to the manufacturer requesting additional data or numerous technical meetings.

As you might imagine, once the case reaches our Office of Chief Counsel, the procedures become more formal. In accordance with Public Law 89-563, the complete process requires that an Initial Determination of noncompliance must first be made, a public hearing is held to afford the manufacturer or any other interested party an opportunity to present their views and then a Final Determination is made.

There were 47 standards in effect in FY 1975 and 23 of these were included in our test program for that year. Some of the standards do not require an actual physical test to determine compliance - a visual examination is sufficient. For the standards which do require testing, we are forced by budget and manpower limitations to establish priorities and direct our efforts to those standards where we feel that our enforcement efforts will be of the greatest benefit. Our compliance testing budget was 3.4 million dollars in FY 1975. The OSE staff consisted of 45 people in FY 1975 with 34 of these being professional and the remainder being clerical support.

There are many standards for which tests were conducted as a part of the complete vehicle from the FY 1968 program through FY 1975. It should be noted that several of these standards require a full-scale crash test into a concrete barrier. In these crash tests we determine compliance with FMVSS No. 204, "Steering Column Displacement," FMVSS No. 212, "Windshield Mounting," and FMVSS No. 301, "Fuel Tank Integrity." Other standards such as FMVSS No. 105, "Hydraulic Brake Systems," require a vehicle track test with instrumentation such as the fifth wheel.

A composite showing the compliance test program for equipment items from FY 1968 through FY 1975 includes items which are tested separately from the vehicle, sometimes referred to as "bench tests." These equipment tests are the ones with which I am most familiar as this is my particular area of responsibility.

Some examples of the types of equipment tests conducted are the whip test on brake hoses, cycling tests on seat belt retractors and these tests, with which I am sure that many of you are very familiar, bead unseat tests on tires and endurance and high speed wheel tests on tires. In 1975 there were 217 vehicle tests conducted with 18 failures for a failure rate of 8.3 percent. There were 2,859 equipment tests conducted with 102 failures for a failure rate of 3.6 percent.

I believe that gives you a fairly good picture of our overall test program and our investigative process. As an example, I would now like to go into more detail on one of our more recently initiated programs - motorcycle helmet testing.

Federal Motor Vehicle Safety Standard No. 218, "Motorcycle Helmets," became effective on March 1, 1974. Shortly thereafter we began planning our enforcement program for the standard. In a competitive procurement, a contract was awarded to the Southwest Research Institute in San Antonio, Texas, and compliance testing was started in September 1974.

The requirements of FMVSS No. 218 are impact attenuation, satisfactory labeling, retention system security, resistance to penetration, elimination of dangerous projections and satisfactory configuration.

On the equipment used to test to the impact requirement, the helmet is required to withstand drops of 72 inches onto a flat surface and 54.5 inches onto a hemispherical surface with accelerations of not more than 400 gs. Also, accelerations in excess of 200 gs shall not exceed a cumulative duration of 2.0 milliseconds and accelerations in excess of 150 gs shall not exceed a cumulative duration of 4.0 milliseconds. There is an instrumentation package used to monitor and record the results. The helmet is also required to resist penetration of a pointed instrument dropped from a height of 118.1 inches. Failure can be determined by examination of the aluminum headform on which the helmet is mounted.

The other requirements of the standard such as labeling, configuration, and elimination of dangerous projections do not require testing. Compliance can be determined by visual inspection.

In summary, I have attempted, this evening, to give you a general picture of the types of testing which are involved in the enforcement of the Federal Motor Vehicle Safety Standards. As you can see, it involves a rather wide spectrum of testing techniques, and some highly sophisticated equipment and instrumentation. However, it provides some very interesting technical challenges.

In the time remaining, I will be glad to answer any questions you may have.

CHAPTER III - GENERAL SESSION

THE ECONOMICS OF NDI IN RETREADING...AN INDEPENDENT SURVEY

James D. Weir and Kay Weir
Tire Press
Culver City, California

ABSTRACT

Exploring the economic justification for NDI in the Retread Industry. Outlining the status of Retreading as a market for NDI Systems. And presenting the results of an independent survey of the requirements and preferences of Retreaders.

There are about 3600 individual retread shops in the United States today. And they undoubtedly comprise the largest potential market for nondestructive inspection systems for tires. However, this market, like any other, must be understood before it can be exploited. The wants and needs of these 3600 highly independent retreaders must be recognized before NDI of tires can successfully make the transition from the laboratory to the retread shop.

We have been intimately involved with many of these shops and would like to briefly explore the retread industry as a market for NDI with you.

Since retiring from full-time, active employment in 1973, Kay Weir and I have been able to pursue many developments in the tire industry that we found interesting. The survey information I will be presenting to you today grew out of our interest in NDI for retread shops and our exploration of retreader attitudes and needs through our newsletter, THE ENDURING CALIFORNIA RETREADER.

First, an explanation of THE ENDURING CALIFORNIA RETREADER, for it seems to need explanation. Perhaps it is best described as the Free Press of the retread industry. We write it as a personal communication to retread shop operators. We give our opinions and observations about whatever is on our minds; from equipment maintenance tips and very personal and practical information about things in retreading, to the state of the economy and the latest "Wise Sayings." It contains the kind of comments we would exchange if we could actually visit these people every week or so.

The ECR is sent occasionally and irregularly to whomever asks for it; and to some who don't. We do not charge for it, and in no way does it compete with the regular trade journals. It makes no pretense at being unbiased.

The readership falls into two categories: retread shop owners and foremen, those to whom we actually address ourselves; and others who have asked to receive it because they want to know what is going on. Or at least our version of what is going on.

The survey about casing inspection and inspection machines was included with ECR #11 and was mailed October 31, 1975. It was kept short and relatively simple to assure a large number of returns. It was designed to implant as well as gather information.

Survey Sample (Table I)

Most of the respondents are from California with 23% from other parts of the United States. All are retreaders and one has a sideline, manufacturing new tire and retread equipment. In all, they produce 8529 retreads per day. Of these 9.7% are truck retreads, 88.8% passenger retreads, and 1.5% specialties (OTR, race, aircraft, etc.).

Comparing these figures to the best estimates of retread shop production in the United States; this survey covers about 1.2% of the shops in the nation and 4.44% of the total national retread production. It further breaks down to 5.57% of the total passenger car tire retread production, 1.73% of the truck, and 1.6% of the specialty retread production. The average shop in our survey produces about three times the national average.

Of those shops who operate passenger shops, 58% are large, producing 101 or more retreads per day day; 24% produce between 41 and 100, and 18% produce 40 or less tires per day.

Forty-five percent of the shops do only passenger car sizes, 38% do both truck and passenger sizes, and 17% are exclusively truck tire treaders.

Most of the respondents who retread truck tires have medium sized operations, doing between 11 and 50 truck tires per day; 45% are in this category, 32% do 10 or less and only 23% are large truck operations doing 51 or more truck treads each day.

Twenty percent report an additional specailty. And 23% of all the responding shops use some precure system.

Radial Production

Of the shops doing passenger tires 42% report doing some radials; 68% of the truck shops do radials. However, of the total production reported in this survey, only 3.74% of the passenger and 14.5% of the truck treads are radials.

Inspection Time

Most of the passenger shops report taking 1 to 3 minutes for casing inspection with the range of reports from 1 to 10 minutes per tire. Truck shops generally report taking 3 to 5 minutes with the range from 2 to 10 minutes. Twenty percent of the truck shops indicate that they use higher inspection standards for their precure systems than for their hot treads.

You must note from this information that there is no such thing as a standard retread shop. Their operations are many and varied.

Adjustment Rates (Line 4)

Reported adjustment rates range from 1/2 to 12% for passenger and 1/4 to 13% for truck. The term "adjustment" means something different to each person using or hearing it. For my purposes, I label as an "adjustment," any casing that has had a new tread applied to it and is found unfit for service anytime during the expected life of that new tread. This includes mold blows and other in-shop failures as well as rapid tread wear, road hazards and policy adjustments. For some retreaders, an adjustment is whatever he is coerced into replacing by a screaming customer and under threat of great bodily harm.

Correlating the reported adjustment rates with the production figures from this survey, I find the adjustment rate for passenger retreads in the United States to be probably 6.49%. And the truck retread adjustment rate to be around 3.54%. These figures compare closely with what I actually see in the field.

Casing Failures (Line 5)

Information from the survey indicates that over 60% of retread adjustments are caused by casing failures. My experience indicates this may be on the low side. These are failures that are caused by problems within the casings that the retreader, with the present state-of-the-art, can not detect before the casing is retreaded. That, of course, is why I am here today.

Our figures indicate that 4.1% of all the passenger retreads and 2.16% of all the truck retreads produced fail because of casing defects. That is about 1.6 million casing defect related failures per year or 6600 failures per working day. More emphatically, casing failures are a $17,000,000 a year problem!

Retreaders' Attitude

Retreaders are unable to control their adjustment rate below a certain point. And I'd like to tell you why: for many years the art of retreading has been developed to the point where a new tread could reasonably be expected to stay on a used casing. But remember, retreading is a recycling industry that requires a used product for its prime raw material. This used product has often been laced with "bombs" over which the treader has had no control. Some of the "bombs" are in the design and material changes that new tire manufacturers initiate and send out into the market. Let me list a few and you'll understand:

1. The S2 and S3 tires of WW II which were virtually unretreadable.
2. The Air Ride tires of the late 40's.
3. The conversion to Rayon.
4. Nylon tires that grew and grew and flat-spotted.
5. Tubeless tires with their separations.
6. Puncture sealing tubeless tires with the goo.
7. The Butyl tire disaster.
8. Two-ply tires.
9. The glass-belted tires we are only now learning to live with.
10. The first generation of steel belted radial passenger tires which we only pretend to know how to cope with.

Other "bombs" are the result of use and misuse during the first tread life.

In addition to these casing problems, retreaders have had equipment and processes unloaded upon them that were filled with promises and little else. Cynics are made, not born. And there are many cynics in the retread industry. Those of you here today who are preparing to take your systems to the retreader must be aware of this cynicism. (Personally, as an old retreader, I think a little paranoia is a healthy thing!)

Back to Today's Casing Problems (Table II)

When analyzing his adjustments, in addition to the field testing, the retreader finds himself doing for the new tire manufacturer, he becomes aware of certain regularly occurring conditions in his failed retreads. This section is directed towards those observations.

This is where the retreader needs NDI. Those conditions listed on this table become visible

THESE ARE QUESTIONS ABOUT CASING INSPECTION AND INSPECTION MACHINES

((There is no need to sign this questionaire but you may if you wish.))

1 WHAT PART OF THE COUNTRY ARE YOU IN? SO CAL 63% REST OF CALIF 15%.
WESTERN U.S. 12 EASTERN U.S. 2½ SOUTHERN U.S. 2½ OTHER 5%.

2 ARE YOU A: RETREADER 100% CASING DEALER — OTHER(specify) AG -1.

3 VOLUME OF CAPS PER DAY: Truck 9.7% Passenger 88.8 OTR ___ Industrial ___.
Aircraft ___ Racing ___ Other(name) 1.5%.

4 WHAT IS YOUR ADJUSTMENT RATE? (Total from all causes including inshop loss.)
Be Honest! Passenger ½-12% 6.49% Truck 1-13% 3.54%. Other 6:.

5 HOW MANY OF THE ABOVE ARE CASING FAILURES? ¼ 2% 1/3 2% ½ 36% 2/3 10% 3/4 50%

6 DO YOU RETREAD RADIALS? Passenger, Yes 42% No ___. Truck, Yes 68% No ___.

7 IF SO, WHAT % OF YOUR TOTAL PRODUCTION IS RADIAL? Truck 14.5% Passenger 3.74

8 INSPECTION TIME PER TIRE (in minutes): Truck ___ Passenger ___ Other ___.

DOES THIS INCLUDE MINOR PATCHING? Yes __ No ___.

25% Do Some Precure.

9 IF YOU DO BOTH HOT & PRECURE, DO YOU USE THE SAME INSPECTION STANDARDS FOR BOTH? Yes 80% No ___. IF NOT, WHICH IS HIGHER? Hot ___ Precure 20%

TABLE I - - - - - - WEIR 1976

10 WHEN ANALYSING YOUR ADJUSTMENTS, HAVE YOU COME ACCROSS THE FOLLOWING:
(This question is related to casing failure only, NOT CAP LIFTS. Casing failure must be considered anytime that you can see cord.)

		OFTEN		SOMETIMES	RARELY	NEVER
A	STEEL BELT RUSTING...	18%	49%	31%	31%	5%
B	CORD FRACTURES.......	33	69	36	20	2%
C	BEADS BENT...........	13	23	10	41	23
D	CASING POROSITY......	10	38	28	41	5
E	BEAD FRACTURES.......	13	23	10	44	18
F	BELTS BROKEN.........	56	84	28	2	2
G	INTRA-PLY SEPS.......	67	95	28	0	0
H.	EXPOSED CORD (top ply)	28	51	23	31	2

TABLE II - - - - - - WEIR 1976

only after a retread has failed. Yet we know that some of these conditions are present in the casing when it is inspected and passed. Currently, casing inspection for retreading is a beauty contest only. I have clients using prime #1 casings exclusively with 7% casing failures while others have 3% casing failures using #2s and 3s.

With our present grading system, the difference between grades is more in the surface condition of the casing, not in its basic integrity. The inspector looks for exposed cords, oxidation, torn beads, nail holes, broken belts, breaks, and separations. But what can he really find? Not much when it comes to the broken belts, breaks, separations, and other conditions listed on this table. As of today, he can be sure that at least 4% of all the passenger casings and 2% of all the truck casings that he inspects will fail because of problems within the casing that he can't see. He knows he is retreading bad casings but he has no way of identifying them.

The responses to the "often" and "sometimes" columns in question 10 were combined to find the most observed conditions in failed retreads. Heading the list by far was intra-ply seps. Not a single respondent indicated that he rarely or never saw intra-ply seps. Next in order were broken belts, cord fractures (breaks), top-ply seps, and steel belt rusting at 49%. Since radial passenger production is only 3.75% of the total, and many of these are fabric belts, the impact of this problem has not been felt by most retreaders.

As a personal note, I made cuts of over 100 steel belted passenger radial casings about a year ago. I found belt rusting in every tire and belt edge separation in more than 75%. The only casings without belt edge separations were those under 175 cross section.

NDI Market Potential

Some clue to the market potential for NDI in retreading can be found in the cost of casing related failures. Truck treaders indicate that 2.16% of all the tires they retread fail because of casing defects they can not find with their current inspection systems. This is over 1/4 million annually. Most truck retreads are on the users' casing which is not normally guaranteed. Therefore, I figure the average truck adjustment at $20 per tire. This gives us a $5,200,000 annual loss.

Passenger treaders indicate that 4.1% of their product will fail from undetected casing defects. That is almost 1.4 million units per year. With a production cost of $7, plus $1.50 for a casing, we have a whopping $11.8 million annual loss.

Conservatively then, since these figures do not include truck casing replacement costs, NDI systems and equipment designers can help the retread industry save $17,000,000 and 5 million gallons of oil each year. Effective NDI systems can reduce the total adjustment to less than 1-1/2% for truck and 2-1/2% for passenger. This would greatly increase the stature and profitability of this re-emerging industry.

Table III

The survey asked in several ways what retreaders would be willing to pay for a machine or system that would reduce their casing caused adjustments by 90%. Question #20 asked for this information directly. The range of choices was from $2,500 to $50,000. The average of responses was for a machine that cost $7,500.

Additionally (line 17) we asked what they would be willing to pay on a per tire basis. Truckers indicate they are willing to pay from 50¢ to $2.00 per tire for 90% accurate NDI. The average response being $1.15 per tire. Personally, I don't feel that they will really part with that much money.

Passenger treaders say they are willing to pay from 10¢ to $1.00 per casing with an average of 29¢. I feel that figure is more realistic and in line with what their adjustments actually cost them. Casing failure adjustments cost the passenger retread industry just under 35¢ per unit. Truck casing problems cost about 43¢ per tire if the casing is not included. If it were added, that figure would nearly double to 85¢ for every truck tire retreaded in the United States.

Most retreaders indicate they would like to have the machine pay for itself in three years, and that they would rather buy than lease the equipment; 92% thought such a machine would be valuable to them and 67% think it could be an advertising advantage. Half the treaders think their product liability insurance costs would not be reduced. Comments returned with this question are further indications of retreaders' cynicism. (Some of these comments are included in the appendix.)

Fifty-one percent of these treaders say they are willing to buy pre-screened casings at a premium price. This could be one way for small shops to make use of an expensive system should that be the result of your development.

Another indication of the retreader's willingness to pay for equipment that meets his need and that he can use, is AMF's Orbitread. It requires a minimum five year lease with some $4000 for down payment and installation plus 4¢ per pound of rubber used. A 100 tire per day passenger shop pays about $40,000 over those five

Any Non Destructive Inspection Machine would be used in addition to your normal inspection process. It is not a substitute but an additional tool. These machines vary in their approach but usually indicate in one way or another, casing integrity. Some indicate actual separations & Other anomalies while other machines indicate the casing's potential for failure.

11 WOULD A MACHINE THAT WOULD REDUCE YOUR CASING ADJUSTMENTS BY 90% BE VALUABLE TO YOU? Yes 92% No 5% ? 3%

12 WOULD YOU EXPECT AN ADVERTISING ADVANTAGE IN HAVING SUCH A MACHINE? ? 8% Yes 67% No 25%.

13 WOULD YOU EXPECT THIS MACHINE TO REDUCE YOUR PRODUCT LIABILITY INSURANCE PREMIUMS? Yes 37% No 50%.

14 DO YOU THINK IT WOULD PAY YOU TO HAVE A MACHINE LIKE THIS? ? 27% Yes 68% No 5%.

15 WOULD YOU BUY PRE-SCREENED CASINGS AT A PREMIUM PRICE? ? 11% Yes 51% No 38%.

16 WHAT KIND OF PERFORMANCE PROOF WOULD YOU REQUIRE BEFORE INSTALLING SUCH A "CASING INTEGRITY MACHINE"?__________.

17 HOW MUCH PER CASING WOULD YOU BE WILLING TO PAY FOR SUCH A MACHINE? (Be Honest!) Truck: 50¢ 39% $1 25% $2 36% $5 —

Passenger: 10¢ 31% 25¢ 38% 50¢ 12% $1 7% Other ? 12%.

18 WOULD YOU WANT THE MACHINE TO PAY FOR ITSELF IN 3 YEARS 63%, 4 YEARS 7%, 5 YEARS 16%.

19 WOULD YOU PREFER TO LEASE OR BUY? Lease 22% Buy 63% 15%

20 WOULD YOU PAY $5,000 26% $7,5000 24% $10,000 18% $20,000 5% $50,000 5%. 2500 5%.

21 FROM WHAT YOU MAY KNOW ABOUT THESE MACHINES, WHICH SYSTEM DO YOU PREFER AT THIS TIME? (Number them 1,2,3,4, in order of your preference.)

1% X-RAY, XEROGRAPHY, NEUTROGRAPHY. (This type, in effect, looks through the casing. It may or may not find seps. It generally is better for finding cord anomalies.)

13 INFRA-RED & HEAT SENSING. (This is generally a test wheel type operation. It may locate seps & gross cord problems.)

85 SONIC, PULSE-ECHO, THROUGH TRANSMITION, ACUSTIC EMISSION. (These may be able to discern between various casing & cord bonds, indicating casing fatigue & integrity. May or may not pick up seps.)

1% LASER HOLOGRAPHY. (Picks up distortion & stress in casing in photographs. May or may not indicate seps.)

22 HAVE YOU EVER USED ONE OF THE ABOVE SYSTEMS? Yes 10% No_____.

If yes, what was your experience?__________.

TABLE III - - - WEIR 1976

years. That is a lot of money and there are a lot of Orbitreads in use.

Survey Data

Table 4 has some of the data upon which this report is based. These are real figures from real shops, shops that will be buying NDI equipment. The columns indicate shop volume, adjustments (in actual numbers of tires per day) what the shop is willing to pay for NDI, and the actual cost of casing adjustments for that shop (using his figures).

Let's look at shop #7. He produces 10 truck and 125 passenger treads per day. His total adjustments are 0.5 truck per day and 6.25 passenger per day. His casing failures are 0.375 per day for truck and 4.69 for passenger. He says he will pay 25¢ or $7800 per year for NDI for his passenger tires. He chose not to comment on an outright purchase price for an NDI system. However, casing failures actually cost him $1875 a year for truck and $9970 for passenger. Casing failures are costing him almost $12,000 a year.

Shop #27 produces 120 truck and 250 passenger retreads a day. He has 4.8 truck and 10 passenger adjustments per day. And 3.6 truck and 7.5 passenger casing failures per day. He agrees to pay 50¢ for truck and 25¢ for passenger NDI. That equals $15,000 a year for truck and $15,625 for passenger. For outright purchase, he considers $10,000 to be the right price. However, his actual casing failure costs are $18,000 for truck and $15,900 for passenger retreading each year.

For another view of the cost of inadequate casing inspection, the "average" shop in the United States produces 38 passenger tires and 13 truck tires per day. For this modest sized shop, casing failures cost $4700 each year.

TABLE IV

	DAILY PRODUCTION & ADJUSTMENT FIGURES						ADJUSTMENT COSTS: RESPONDENTS WILLING TO PAY					ACTUAL COST OF CASING ADJUSTMENTS $	
line #	TOTAL PRODUCTION		ADJUSTMENTS (all causes)		CASING FAILURES		PER CASING $		PER YEAR $		FOR MACHINE PURCHASE		
	T	P	T	P	T	P	T	P	T	P	$	T	P
1		150		6.00		3.00							6,375
2	10	150	0.50	7.50	0.25	3.75					5,000	1,250	7,970
3		140		9.80		6.53		.10		3,500	10,000		13,875
4	7		0.21		0.15		2.00		3,500		NO	750	
5	50		5.00		1.25		.50		6,250		2,500	6,250	
6		60		6.00		3.00		.25		3,750	----		6,375
7	10	125	0.50	6.25	0.375	4.69		.25		7,800		1,875	9,970
8		350		14.00		10.50		?					22,300
9	5	25	0.25	1.25	0.125	0.63	.50	.10	625	625	5,000	625	1,340
10		350		35.00		17.50		.25		21,875	50,000		37,200
11	30		0.90		0.45		2.00		15,000		5,000	2,250	
12	100	600	2.00	72.00	1.00	36.00		?			?	5,000	76,500
13	100		2.30		1.73						5,000	8,650	
14	70	100	1.40	0.50	0.70	0.25	1.00	.10	17,500	2,500	7,500	3,500	530
15	70	20	4.20	1.20	2.80	0.80	2.00	.50	35,000	2,500	?	14,000	2,500
16		150		7.50		5.63		1.00		37,500	7,500		12,000
17	25	100	0.13	3.00	0.06	1.50	2.00	.50	12,500	12,500	10,000	300	3,200
18	25		0.40		0.30		1.00		6,250		5,000	1,500	
19		7		0.14		0.10		1.00		1,750	7,500		212
20		100		6.00		4.00		.25		6,250	7,500		8,500
21		360		18.00		9.00		.10		9,000	5,000		19,125
22	10	20	0.50	2.00	0.37	1.50	2.00	.25	5,000	1,250	NO	1,850	3,200
23	10	40	0.10	0.40	0.05	0.20	?	?			?	250	425
24	10		0.40		0.20							1,000	
25		100		2.00		1.50		.25		6,250			3,200
26	24	85	0.06	0.42	0.02	0.15	1.00		6,000			250	320
27	120	250	4.80	10.00	3.60	7.50	.50	.25	15,000	15,625	10,000	18,000	15,900
28		350		42.00		21.00					5,000		44,625
29		600		27.00		13.50		.50		75,000			28,700
30		675		54.00		40.50		.25		42,200	10,000		86,000
31		160		16.80		12.60		.25		10,000	20,000		26,775
32	30	20	1.35	0.80	1.22	0.72	.50	.10	3,750	500	7,500	6,100	1,530
33	10	450	1.30	27.00	0.87	18.00		.25		28,125	2,500	4,350	28,250
34		60		3.30		2.48							5,270
35	50		1.50		1.13		.50		6,250		5,000	5,650	
36		300		19.50		14.63					5,000		31,100
37	30	75	0.30	2.25	0.23	1.69	.50	.10	3,750	1,875	7,500	1,150	3,600
38		300		24.00		18.00		.10		7,500	10,000		38,250
39	20	200	1.00	15.00	0.75	11.25						3,750	23,900
40	12	1100	0.24	50.60	0.18	37.95		.10		27,500	7,500	900	80,600

Desired Features (Table V)

No matter how good you think your NDI system is, I believe you must listen to what the retreader is asking for. He, after all, is the one who is going to pay for it. And he, most of all, is the one who knows what the requirements of his shop operation are.

We found that speed of operation is the most desired feature for any NDI machine or system. I think that speed of operation should include not only through-put but also real or near real-time operation. Next desired is simplified operation. Tied for third, and we were surprised, (we'd expected they would be first and second) were cost and ease of operation.

The least desired of the features we asked about was an oscilloscope. However, one respondent suggested that it would be great to dazzle his customers.

The nondestructive inspection of tires is a reality. It can be done. We are meeting here for these three days to discuss the many ways it can be done. And, though new methods are constantly being developed, a number of systems have matured to the point where it is time to consider their practical application in the field. As I pointed out in my opening comments, retreading is probably the biggest field for these systems.

Retreaders need NDI. Retreaders can pay for NDI. And those of you here with laboratory matured NDI systems need retreaders so that you can now make your research pay for itself. If you recognize the retreader's needs; if you listen to what he has to say to you; if you accept and work around his limitations, economic and otherwise; you can establish a mutually rewarding relationship. You will have a good customer for your product. He will buy and use your machines.

I'd like to close with a comment from one of the respondents to our questionnaire. "You can only add so many steps to the process, each of which costs money, before a retread costs as much as a new tire....Your machine would have to be simple enough for the "typical retreader" to use without the boss having to take over the inspector's job. There have been enough good ideas that didn't work sold to the retreading industry to last a lifetime."

QUESTIONS AND ANSWERS

Q: I am interested to know how the retreader goes about limiting an age for which he will no longer retread?

A: Certain limitations in passenger tires have been set upon us by the type of tire that is being accepted. We can only retread DOT-approved tires which are certain sizes. From 1968 on, I believe.

23 FROM WHAT YOU KNOW ABOUT THE LIMITATIONS OF NDI MACHINES, INDICATE THE IMPORTANCE TO YOU OF THE FOLLOWING FACTORS:

	NOT IMPORTANT	MAYBE	VERY IMPORTANT
A SIZE OF MACHINE	11%	39%	35%
B COST OF MACHINE	0	15	81
C SPEED OF OPERATION	0	8	88
D EASE OF OPERATION	3	12	81
TEST READOUT:			
E DETAILED INFORMATION	27	35	15
F SIMPLIFIED INFORMATION	0	3	85
G OSCILLOSCOPE	42	23	12
H DIGITAL READ OUT	15	42	15
I LIGHTS (go, no-go)	3	31	58
J PRINTED RECORD OF TEST	23	31	19

24 WOULD YOU BE WILLING TO KEEP THE ROCORDS, ETC., NECESSARY FOR PARTICIPATING IN FIELD TESTS OF SUCH A MACHINE? Yes 100% No_____.

TABLE V - - - - - WEIR 1976

James D. Weir
Inc.

NDI MACHINES IN RETREADING, SURVEY DATA

SHOP PRODUCTION.... Of those shops reporting:
35% do both truck and passenger.
17% do only truck
45% do only passenger (may have small specialty)
20% have additional specialty (OTR, race, aircraft, ind.)
82% produce at least some passenger . (ajd rate 6.5%)
55% produce at least some truck. (adj. rate 3.5%)

SHOP VOLUME........
18% Small Passenger (40 or less/day)(adj rate 4.66%)
24% Med Passenger (41 to 100/day)(adj rate 3.8%)
58% Large Passenger (101 or more /day)(adj rate 6.76%)

32% Small truck (10 or less/day)
45% Med Truck (11 to 50/day)
23% Large truck (51 or more)

Total volume of survey = 4.40% of all U.S. retread production.
← Truck 1.78% U.S. Pass 6.57 % 1.6% Spec.
25% use some precure system.

INSPECTION TIME.... (per tire)
TRUCK
2-3 minutes with patching..-......16%
2-3 minutes without patch.........26%

4-5 minutes with patching.....16%
4-5 minutes with-out patch....21%
6-10 minutes with patching....16%
6-10 minutes without patch.... 5%

PASSENGER
1 minute or less with repairs......11%
1 minute or less without repairs...26%

1½-3 minutes with repairs.....22%
1½-3 minutes without repairs..26%

3½-6 minutes with repairs....7%
3½-6 minutes without repairs.4%

10 minutes without repairs..4%

14.5% of truck retread production is radial.
3.74% of passenger retread production is radial.

42% of the passenger shops do some radials (from 2 to 30%)
68% of the truck shops do some radials. (from ½ to 20%)

25% of Pass. shops reporting doing radials do less than 10/d
25% of Truck shops reporting doing radials do less than 2/da

TRUCK..... Adjustment rate: 3.53%
61.3% of these adjustments are reported to be caused by casing failures.
2.16% of truck retreads will fail because of casings.
(256,000 truck retread failures)
($5,200,000 per year cost)
($20 average cost to produce a truck retread. Not including casing.)
Truckers are adjusting about 100 retreads/day because of inadequate casing inspection systems.

PASSENGER..... Adjustment rate: 6.49%
63.1% of these adjustments are reported to be caused by casing failures.
4.1% of passenger retreads will fail because of casings.
(1,400,000 failures/ year)
($11,800,00 per year cost)
($7 production cost and $1.50 casing)
Passenger treaders are adjusting about 5,600 retreads/day because of inadequate casing inspection systems.

If casings could be guaranteed perfect, retreaders' adjustment rates could be reduced to 1.37% for truck and 2.39% for passenger.

COMMENTS FROM SURVEY SHEETS

QUESTION NUMBER

10-C-2 (Beads Bent) Answer: Sometimes. "Get more stripped beads."

#11 WOULD A MACHINE BE VALUABLE?.."Depending on cost on acquiring and operation.

#12 WOULD YOU EXPECT ADVERTISING ADVANTAGE?.."Yes, Wholesale only. No point of sale benefit."

#13 REDUCE INSURANCE PREMIUMS?..."No. Did 55 MPH lower your insurance rates?"

"Doubtfull. Most ins. co. do not reduce business."

#15 BUY PRESCREENED CASINGS?..."No. Who would do it? How would you be sure?"

"Yes if they are warantwed."

"No. Not trusting is my problem."

#16 PERFORMANCE PROOF REQUIRED..."Installation & 90 days usage of this machine."

"Time tested"

"100% better than what we now use."

"Sell with take back or lease with escape clause."

"Prefer in shop"

"A well tested machine with retreads on vehicles extended period of time."

"Testing"

"Much proof"

"Reduced insurance based upon proven reduced adjustments."

"I'm from Missouri (figuratively)."

"Inventory of supplier."

"Government approval or constant use approval."

"(1) Lab results (2) Inh use test period (3) Speed of machine."
"Infield testing of machine"

"DOT Approval"

"better than 95% accuracy."

"1 year testing in shop"

"Cross checks with pull tests and destruct testing."

"Considerable reduction in ply separations"

"6 mo to 1 yrs use by a "custom" capper. (one who caps customers cassings retail)

#19 LEASE OR BUY?,..."Depends on cost AMF had good idea, lease & give service on complex machine."

"Either or. Dependent upon amassed value of machine after 90 day evaluation."

#21 WHICH SYSTEMS PREFER AT THIS TIME?
Don't know
Not Knowledgable
Don't know enough to choose

#22 USED MACHINE BEFORE? Yes. "Good but needed improvement"

"Cost = NA, Result questionable"

#24 WILLING TO FIELD TEST? "Yes. Depends on how much trouble it would be."

#25 COMMENTS: "Good job, Jim."

"Those ((questions)) that are not answered would be guesswork. This area is new and no previous thought given to same."

"Am fearful of the price and time required per tire."

"How sofistigated will the retread industry become before the user "industry" (truck, off road) is made aware of those specific new tires (by name and grade) that they purchase(d) are prone to (or more prone to) failure then another make and grade offered?.........By whom shall this information come to the user?"

"Build it, test it, prove it, I'll buy it & sell it."

"Adjustment ratio abnormally high due to: 1. Former shop manager not using proper systems. 2. Experiments in A-2 kettle retreading that did not work out. Prior years we used a 4% of shop selling price to our store (about 30% on Goodyear list price) and put into retread reserve account. Adjustment credits issued to customer offset this account. At end of year we would kick balance into profit. In the past we allways had a balance leaving 2½-3% true adjustment. Not this year. Good shop practice there should result in adj % of about 2-2½%. Machine could possibly improve 1%. Save maybe $4,500 per year less the cost of operating the thing. How much is it worth ???"

"Major determining factor will have to be price. May require group use of machine in geographic area."

"I plan to take on pre-cure in next year. I have no experience with radial capping....I hope pre-cure will include radial capping (trk & pass)."

"The machine produced by the Fed government & introduced at Louisville, Ky last spring may well be a beginning to the answer. Do not believe it is total ans. yet. Perhaps that combined with a floarascope such as older Doctors had might be a direction to follow."

"For the few caps we do this machine would not be economical."

"You can only add so many steps to the process, each of which costs money, before a retread costs as much as a new tire. We sent our $5,000 casing conditioner back, we junked our $5,000 Fuller automatic venter. In our area most people with automatic presses have sold them or gone broke. Your machine would have to be simple enough for the "typical retreader" to use without the Boss having to take over the Inspector's job. I went to an auction in Texas 6 months back and saw an IRI extruder builder sell for $800.00 and an IRI press for $200.00. There has been enough good ideas sold to the retreading industry that didn't work to last a lifetime."

SHORT DURATION TREAD WEAR MEASUREMENTS OF 7.00-16 LW (6 PR) MILITARY NDCC TIRES

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ABSTRACT

A series of wear tests using NDCC military 7.00-16 tires were performed on Calspan's Tire Research Facility (TIRF) with the objective to develop an efficient test methodology that would permit the determination of a tire's wear loss after only a few hours' run of normal severity. This required the development of an accurate electromechanical wear measuring device and of a short-duration wear run technique. After systematic elimination or reduction of all major sources of experimental errors, the influences of tire pressure, load, slip angle, and driving and braking torque on tread wear were investigated. The agreement between wear data measured on TIRF and corresponding data measured in road tests (Yuma Proving Ground) was satisfactory. Suggestions are made for a second-phase program.

INTRODUCTION

Wear resistance is one of the most important properties of pneumatic tires, not only because it determines a tire's useful life but also because it is related to its traction properties and, of course, to its safe use.

Four different techniques have been developed in the past for studying the wear properties of tires, all with some virtues, but none satisfactory. *Laboratory* tests of small tread samples are widely used to assess the influence of various tread compounds on tire wear resistance; they fail to reproduce the rather complicated tread motions in the contact area but, nevertheless, produce in short time valuable inputs for compound improvements. For predicting the actual wear life of a given tire, however, testing small tread samples is of little use.

Tire road tests, on the other hand, have the great advantage of exposing the tire (and not just a sample) to real-life conditions, if they are conducted under *normal* (non-accelerated) wear conditions. They reflect, in "natural" fashion, the many influences of driver, vehicle, roadway, traffic, environment, etc., on tire wear. Road tests are usually run with two types of tires -- test tires and control tires. By exposing both test and control tires simultaneously to the same set of (uncontrollable and often rapidly changing) service parameters, their influence can be reduced to a level of acceptable accuracy. To assess the attainable accuracy, consider the results of recent road tests (Figure 1). Two radial tires of the same brand were road tested on the same test course, 500 miles a day for 16 days. After completion of each daily run, the average reduction of groove depth was measured for each tire. The results indicate a large day-to-day fluctuation not only of the wear rate (Figure 1a), but also of the wear rate differences between the two tires (Figure 1b), due to unavoidable changes in weather, driver behavior, road conditions, and other uncontrollable factors. It is obvious that these large fluctuations necessitate rather long test distances (here, 8000 miles) with attendant long test times (here, 16 work days) and high costs.

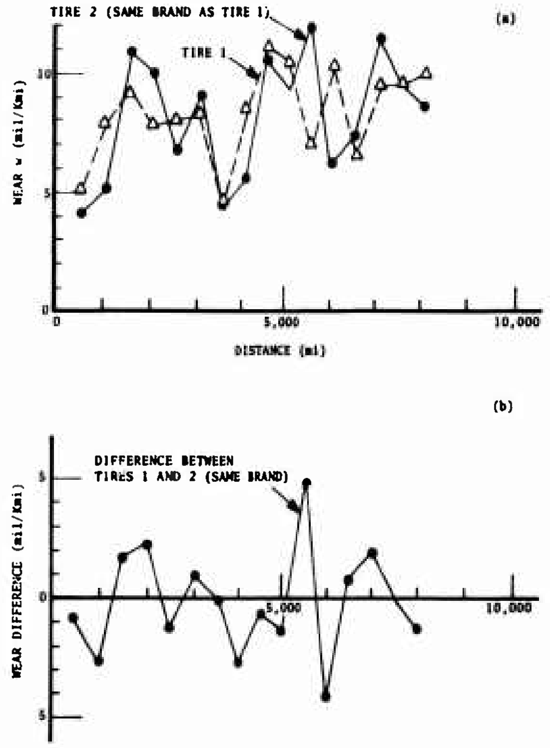


Figure 1. Results of road wear tests (from ref. 1).

Attempts to reduce the high cost of road testing under normal wear conditions have not yet been very successful. *Mathematical wear models* are in their infancy; at their present stage of development, their predictive power is very limited. Wear testing under severe wear conditions, so-called *"accelerated" wear*, another alternative, is not satisfactory either. Testing under severe conditions yields considerable wear after only a few hundred miles of tire travel and thus reduces test cost; but since test results failed to correlate well with results from normal wear testing (as we will see), the usefulness of accelerated wear testing is questionable.

Clearly, a (fifth) method is needed that would combine the advantages of controlled, short-term laboratory tests with the real-life wear conditions of road testing. Until recently, the road systems of laboratory tire testers were severely deficient; the surface was either curved (drums) and thus unable to reproduce the correct road geometry, or very short and/or of low speed (flat-bed test machines) and hence incapable of generating realistic wear conditions. With Calspan's Advanced Tire Research Facility (TIRF), however, these disadvantages were removed. TIRF features a flat road surface with a speed range up to 200 mph. Also, since all external wear parameters such as slip angle, load, and speed are tightly controlled, large data fluctuations -- the major obstacle to short-duration tests under normal wear conditions -- are avoided. Therefore, an opportunity was offered for the first time to test tires on an indoor facility such as TIRF or a ~~similar (simpler) machine under realistic (i.e.,~~ not accelerated) wear conditions, at test durations much shorter than those necessary for road tests.

The following study is primarily concerned with the development of an efficient test methodology that would permit the measurement of a tire's wear loss after a few hours' run at normal severity with an accuracy of less than one mil (0.001 inch = 25-μm). Ultimately, the short duration indoor wear technique is expected to deliver low-cost wear data for wear cycles (varying speed, slip angle, load, camber angle, etc.) patterned after actual wear conditions. The following study is a first step toward that goal.

DEFINITION OF NORMAL WEAR

Tread wear is defined as the gradual loss of tread rubber through tire usage on the road. The loss of rubber can be expressed as loss of groove depth, or tire weight, or tire volume; or it can be characterized in terms of expected tread life. Here, wear is expressed as loss in tread depth in mil per kilomile (1 kmi = 1000 miles) traveled.

$$\text{wear} \quad w = \left\{ \frac{\text{loss in tread dpeth}}{\text{distance traveled}} , \; \frac{\text{mil}}{\text{kmi}} \right.$$

Since wear is closely related to tire slip, normal wear in city and highway driving can be assessed by an evaluation of the slip an automobile is encountering in normal driving. We performed such an evaluation using data of recent investigations by Veith [2] and Chiesa [3]. Veith made a survey of the longitudinal and lateral accelerations experienced by an automobile driven in cities, on rural roads, and on highways. From his data, we computed in an approximate way the distributions of slip angle and longitudinal slip, Figures 2 and 3. For city driving, the slip angle distribution shows two peaks. The first peak at the small value of the slip angle of 0.07 degree can be associated with the small steering corrections necessary to keep the car on a basically straight course. The second peak at about 1.3 degrees can be related to major directional changes (for instance, right angle turns). For interstate highway driving, a distinct peak shows at about 0.2 degree, presumably caused by correctional steer inputs at higher speeds. A very small peak is apparent at about one degree, perhaps produced by passing maneuvers. If we postulate that severe wear is associated with slip angle frequencies

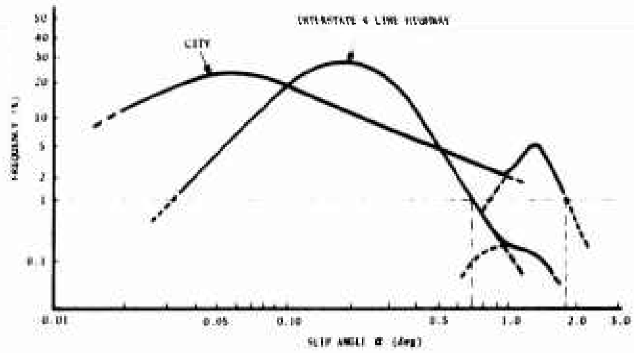


Figure 2. Slip-angle distribution of a passenger car for normal city and highway journey patterns (adapted from ref. 2).

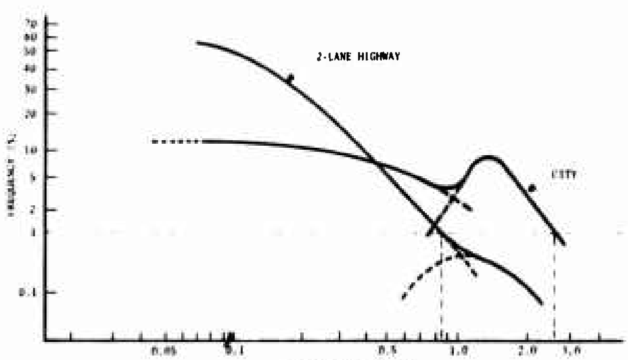


Figure 3. Longitudinal-slip distribution of a passenger car for normal city and highway journey patterns (adapted from ref. 2).

smaller than one percent, then according to Figure 2 all slip angles smaller than 2 degrees must be considered causing normal wear.

The distributions of longitudinal slip (braking and driving) are similar to those of slip angle, Figure 3. If we postulate again the frequency of one percent as bounding the normal wear regime, all longitudinal slip values smaller than 2.5% are defined as causing normal wear.

In the light of these diagrams, then, normal wear takes place at slip angles less than 2 degrees and at longitudinal slip values less than 2.5%; wear occurring at larger values must be considered severe, i.e., outside the regime of normal driving conditions.

These conclusions are confirmed by test results presented by Chiesa and Ghilardi [3] who determined tire wear on roads of different driving severity. The driving severity was expressed in terms of the 99th percentile acceleration (lateral and longitudinal); if 99% of the accelerations experienced by the vehicle under given driving conditions were smaller than 0.1 g, the course was considered of low severity, with a wear rate of 7 mil/kmi; corresponding accelerations and wear rates for courses of medium and high severity were defined at 0.2 g (16 mil/kmi wear) and 0.4 g (70 mil/kmi wear), respectively. From Chiesa and Ghilardi's data, we estimated the 99th percentile slip angles and longitudinal slip values, Table 1. Again, normal wear under low and medium driving conditions occurs at slip angles below 2 degrees and at longitudinal slip values below 2.5 percent. Slip angles above 2 degrees and longitudinal slip values surpassing 2.5% are considered of high severity.

High severity and low severity driving appear to be associated with different wear mechanisms. Many wear tests revealed that under severe wear conditions the wear rank order of two tires establish under normal wear conditions can be reversed. Figure 4 gives an example. Two tires of different make, a test tire and a control tire, were wear-tested under severe and under normal conditions on the same test course (Reference 4). Normal wear was achieved by running the tires on a straight course; severe wear, by running them at various speeds on a 123-foot circle. We evaluated the given test data in terms of slip angle, and plotted them (on log paper, to cover the large range of wear rates) as function of wear rate, w, in mil/kmi. The resulting curves show that at low and medium wear severities, the test tire experiences less wear than the control tire; at higher wear severities, the ranking is reversed. Hence, if run on a highway under normal driving conditions, the test tire would rank higher than the control tire. Run under accelerated (severe) wear conditions, the control tire would outrank the test tire.

Under these circumstances it is not surprising that attempts to correlate normal and severe wear rates have failed. Figure 5 gives an illustration [5]. Wear tests were conducted on a route in Nevada with the objective to establish a correlation between tire wear rates experienced on automobiles (normal wear) and wear rates generated on towed trailers with the wheels set at a slip angle of 2.5 degrees (severe wear). The tires included bias-ply, bias-belted, and radial-ply constructions. Figure 5 demonstrates convincingly that for the tires tested no satisfactory correlation could be established between normal and severe wear rates; the ration w_{normal}/w_{severe} fluctuates between 1:20 and 1:80. We maintain, therefore, that to predict the wear resistance of tires, they must be tested under normal wear conditions.

Table 1. MAXIMUM VALUES OF SLIP ANGLE α AND LONGITUDINAL SLIP S RECORDED ON ROADS OF DIFFERENT DRIVING SEVERITY (AFTER REF. 3).

Road Severity	α deg	S %	Wear Rate mil/kmi
low	1.4	1.2	7
medium	1.8	2.1	16
high	3.3	2.9	70

low - 99% of accelerations <0.1 g (longitudinal and lateral)
medium - 99% of accelerations <0.2 g (longitudinal and lateral)
high - 99% of accelerations <0.4 g (longitudinal and lateral)

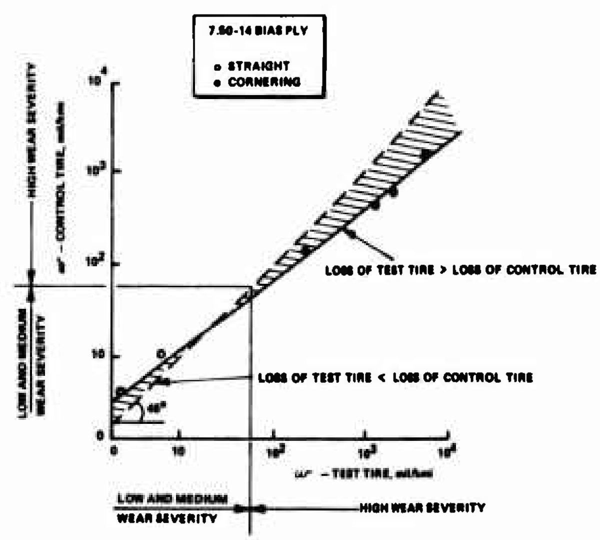


Figure 4. Influence of test severity on tire wear ranking (adapted from ref. 4).

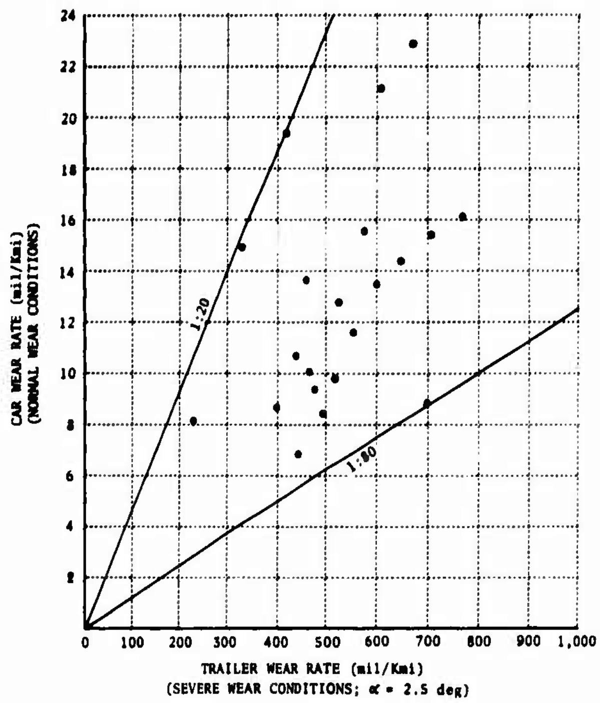


Figure 5. Correlation between normal-wear and accelerated-wear data for different tires (adapted from ref. 2).

TEST FACILITY

A photograph of the TIRF facility is shown as the frontispiece to this report; a dimensional view of the factility is shown in Figure 6. The primary features of the machine are:*

Tire Positioning System

The tire, wheel, force sensing balance and hydraulic motor to drive or brake the tire are mounted in the movable upper head. The head provides steer, camber, and vertical motions to the tire. These motions (as well as vertical loading) are servo controlled and programmable for maximizing test efficiency. The ranges of the position variables, the rates at which they may be adjusted, and other information are shown in Table 2.

Roadway

The 28-inch wide roadway is made up of a stainless steel belt covered with material that simulates the frictional properties of actual road surfaces. The belt is maintained flat to within 1 to 2 mils under the tire patch by the restraint provided by an air bearing pad which is beneath the belt in the tire patch region. The roadway is driven by one of the two 67-inch-diameter drums over which it runs. The road speed is servo controlled; it may be programmed to be constant or varied.

*A more complete description of this facility will be found in Ref. 6.

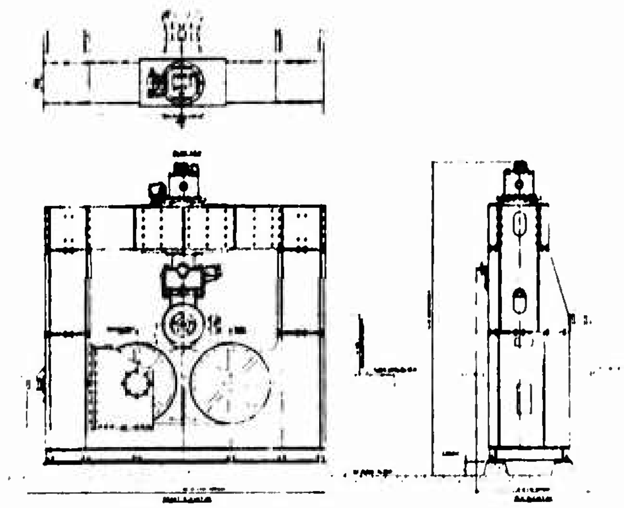


Figure 6. Tire research machine.

The test surfaces used on TIRF are made from a commercially available proprietary material called *Safety Walk*.* The surface consists of a backing sheet treated with contact cement used to adhere it to the stainless steel belt. On the working side, a silicon carbide type of grit material is set in an epoxy type cement. This material is specified by its reflectance which we have found to be related to its microtexture and wet skid number. Standard practice is to use a surface with an initial wet skid number greater than the desired test value. The surface is then stoned with a grinding stone. The stoning serves to break off those sharp asperities which extend appreciably above the others. Stoned surfaces do not abrade the tire surfaces excessively, and they are stable under normal usage. Scanning electron microscope (SEM) photos have been taken of some of the surfaces used. Figure 7 shows SEM photos of one of the materials used in both the "as-received" and "after-stoning" condition.

Schonfeld of the Ontario Ministry of Transportation and Communications has developed a method of photo-interpretation of pavement skid resistance [7]. Samples of our material have been analyzed by Schonfeld who calculated skid numbers in general agreement with values which had been measured. The texture parameters used by Schonfeld are height, width, angularity, distribution and harshness of projections, and the harshness of the surface between projections. He classified the surface in terms of the apparent height and angularity of the microprojections: polished, smooth, fine-grained, coarse-grained subangular, and coarse-grained angular. A fine-grained surface has microprojections approximately 1/mm high while coarse-grained surfaces (angular or subangular) have projections approximately 1/2-mm high or

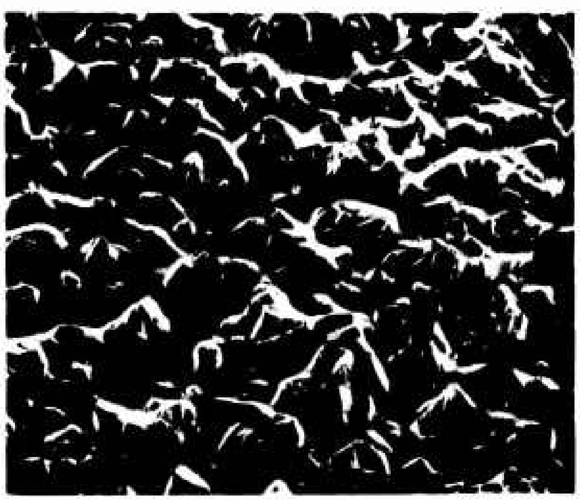
*Manufactured by 3M Company.

Table 2

TIRF CAPABILITIES

CHARACTERISTIC	RANGE
TIRE SLIP ANGLE (α)	$\pm 30^{\circ}$
TIRE CAMBER ANGLE (γ)	$\pm 30^{\circ}$
TIRE SLIP ANGLE, RATE ($\dot{\alpha}$)	10°/sec
TIRE CAMBER ANGLE RATE ($\dot{\gamma}$)	7°/sec
TIRE LOAD RATE (TYPICAL)	2000 lb/sec
TIRE VERTICAL POSITIONING	2"/sec
ROAD SPEED (V)	0-200 mph
TIRE OUTSIDE DIAMETER	18.5" to 48"
TIRE TREAD WIDTH	24" MAX.
BELT WIDTH	28"

a. As-received



b. After stoning

Figure 7. Scanning electron microscope photos (15X) of safety walk surface.

higher. The Safety Walk surfaces fall between fine-grained and coarse-grained with about two-thirds of the projections being more than 1/4-mm high.

A unique feature of TIRF is the ability to carry out tests under wet road conditions. A two-dimensional water nozzle spans the roadway. This nozzle has an adjustable throat which can be set to the desired water depth. The flow through the nozzle is then varied by controlling the water pressure. At each test condition, the water film is laid on tangential to the belt at belt velocity. The film thickness may be varied from as low as 0.005 inch up to 0.5 inch.

Tire-Wheel Drive and Balance System

A drive system which is independent of the roadway drive is attached to the tire-wheel shaft. This separate drive allows full variation of tire slip both in the braking and driving modes. The tire slip ratio, referenced to road speed, is under servo control.

A six-component strain gage balance surrounds the wheel drive shaft. Three orthogonal forces and three corresponding moments are measured through this system. A fourth moment, torque, is sensed by a torque link in the wheel drive shaft. The load ranges of the basic passenger car and truck tire balances are shown in Table 3. Transfer of forces and moments from the balance axis-system to the conventional SAE location at the tire roadway interface is in the data reduction computer program.*

System Operation

Data Acquisition Program (DAP) Control

The data acquisition program (DAP) is a software system which controls machine operation and logs data during tests. DAP controls test operations by means of discrete setpoints which are generated in the computer by the program. These setpoints are sent to the machine servos which respond and establish tire test conditions. After the setpoints are sent to the servos, a delay time is provided which starts after the machine variables

Table 3

BALANCE SYSTEM CAPABILITY

COMPONENT	PASSENGER CAR TIRE BALANCE	TRUCK TIRE BALANCE
TIRE LOAD	4000 lb	12,000 lb
TIRE TRACTIVE FORCE	±4000 lb	8000 lb
TIRE SIDE FORCE	±4000 lb	8000 lb
TIRE SELF ALIGNING TORQUE	±500 lb ft	1000 lb ft
TIRE OVERTURNING MOMENT	±1000 lb ft	2000 lb ft
TIRE ROLLING RESISTANCE MOMENT	±800 lb ft	400 lb ft

*More detailed information of the balance systems are their calibration may be found in Ref. 6 and 8.

have reached a steady state value within predetermined tolerances. This allows the system to stabilize before data are taken. After data are taken, the next set of test conditions is established and testing continues.

One or two variables can be changed during DAP testing. The other test parameters are kept fixed throughout the test. Up to twenty data points can be used for each variable in a run.

A data reduction program is used to operate on the raw data collected during testing. These new data are reduced to forces and moments in the proper axis system and all variables are scaled to produce quantities with engineering units. Raw and reduced data are temporarily stored in a disc file. Both reduced and raw data can be transferred to magnetic tape and maintained as a permanent record.

Reduced data points can be listed, plotted and curves can be fitted to the points. All of the standard Calspan plots can be generated from DAP test data.

Data lists and plots are displayed on the oscilloscope screen of a CRT console. Hard copies of this information can be made off this display.

Continuous Sampling Program (CSP) Control

The continuous sampling program (CSP) is a software system which controls machine operation and continuously logs data during tests. Test variables can be constant or changed at rapid rates. One or all variables can be changed during a test. Data can be sampled at rates up to 100 samples per second. Pauses are used so that data can be logged during desired intervals of the test.

CSP testing can be conducted quickly which in turn reduces tire wear during severe tests. The high rate of data sampling also permits limited dynamic measurements to be made during testing.

Two parameter plots of data can be made. Carpet and family plots of test data cannot be made with this program at the present time. CSP data will also reflect time effects if tire characteristics are a function of the rate of change of testing variables.

Data reduction is accomplished in a manner similar to that employed in DAP testing.

Tread Wear Testing on TIRF Under Normal Wear Conditions

The advantage of tread wear testing under normal wear conditions (slip angle < 2 degrees, longitudinal slip < 2.5%) on an indoor testing machine such as TIRF instead of on the road is evident: most factors contributing to wear can be tightly controlled. For instance, wear of a given tire can be be studied as a function of

- Inflation Pressure
- Vertical Load
- Slip Angle (Cornering)
- Inclination Angle
- Road Velocity
- Slip or Skid (Driving or Braking)
- Tread Depth

It could be argued that wear testing on TIRF is qualitatively different from, and therefore inferior to, road testing in one important aspect: a vehicle on the road "seeks" its way by a "natural process of continuous adaptation to the everchanging external inputs, whereas on TIRF all tire factors are fixed during a test run. Hence, on the road, the tire is subjected to essentially transient conditions, whereas on TIRF it experiences only steady-state conditions. In the light of TIRF's capability to simulate transient conditions, however, this argument does not hold. The influence of many factors such as steering system suspension system, driver habits can be simulated by controlled time-dependent inputs. In fact, almost all parameters that a tire "sees" can be factored into a test cycle in a controlled fashion (except for a few weather inputs such as slush, snow, and ice). Table 2 indicates that slip angle as well as camber angle and vertical load can be varied rapidly, and so can road speed. TIRF's strength is its capability to quickly produce large sequences of tire service factors in a rigidly controlled fashion. Slip and inclination angles can be controlled within 0.03 degree; and tire and road speeds, within 0.08% (at 50 mph). Both tolerances are sufficiently small to ensure well-controlled wear tests under normal wear conditions (i.e., at small slip values). Similarly good accuracies are obtained for all other parameters controlled and recorded by TIRF such as inflation pressure, forces, moments, torque, and loaded radius.

Road tests are inherently incapable of yielding more than a few data points per tire; due to unavoidable "noise" in the form of weather changes, varying road conditions, driver inputs, vehicle feedbacks, etc., the acquisition of each datum point takes up a good part of the tire's total tread life. TIRF is largely free of this "noise." Therefore, the minimum test duration can be substantially reduced provided a short-duration test technique can be developed. The minimum duration of a wear test on TIRF is dictated by the accuracy of TIRF and the accuracy and test duration of the measuring technique, as discussed in the Experimental Errors section.

PROGRAM OBJECTIVES

The major objecties of the program were to

> Develop an electromechanical device that would measure losses in tread height with an accuracy of one mil or better.
>
> Establish a short-duration wear test methodology under normal (not accelerated, or severe) wear conditions.
>
> Determine relations between tire wear and load, slip angle, longitudinal slip (braking, driving), inflation pressure, and speed

Only one tire type was to be used -- a 7.00-16 LW military tire with NDCC tread pattern. Later, under a follow-on program, the test methodology worked out under this program was to be extended to include a larger variety of military tires.

WEAR MEASURING DEVICE AND WEAR PROCEDURE

To measure the change in tread height, we developed a simple mechanical-electrical device. Figure 8 indicates the measurement principle. The rigid frame of the instrument supported by the base area of the tread grooves establishes a fixed reference system unaffected by wear. The position of the wear surface with reference to the frame is measured at points A, B, C, and D by four linear variable differential transformers (LVDT's). Wear at the four points is determined by recording the LVDT positions before and after a wear run, as indicated in Figure 9. A picture of the device is shown in Figure 10.

The tread surface geometry is measured by placing the instrument successively at 12 stations around the tire (numbered 1-12) and three stations across the tread (numbered 13-15). With four surface measurements per instrument position, the total number of tread measurement points is 144. Figure 11 shows the distribution of measurement points

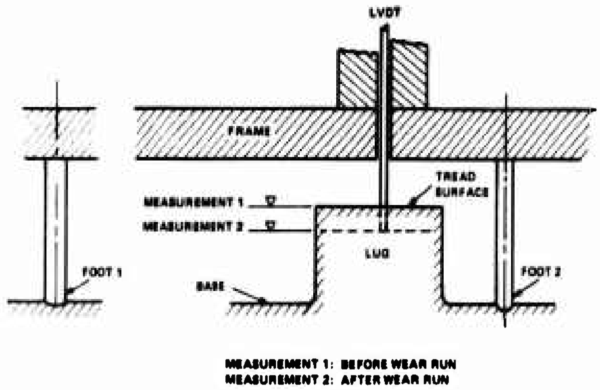


Figure 9. Wear measuring technique (schematic).

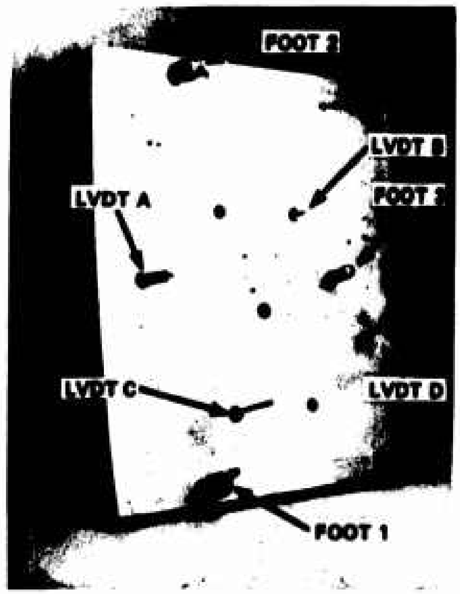


Figure 10. Wear measuring device.

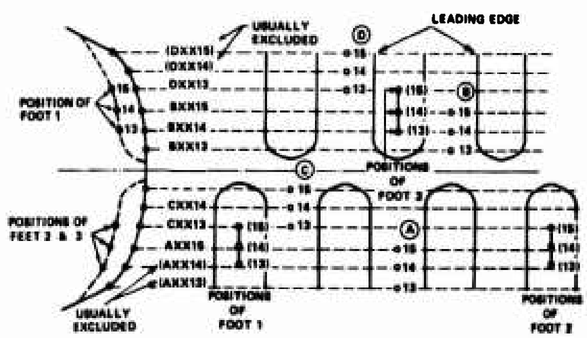


Figure 11. Distribution of wear measurement points at any one of the 12 stations around tire (XX from 01 to 12) total number of points = 12 x 12 = 144.

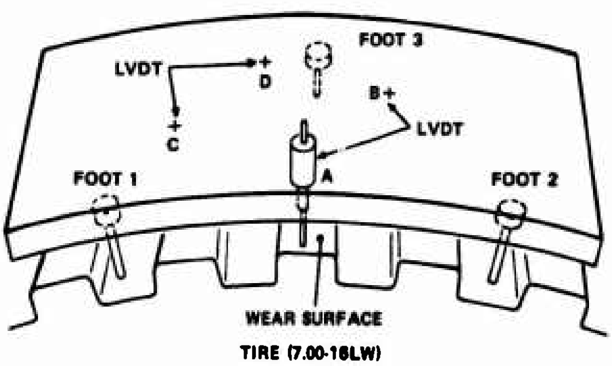


Figure 8. Wear measuring device (schematic).

for the three stations (13-15) across the tread. Each point is identified alphanumerically. For instance, A 09 14 designates the position of LVDT A at the angular station 09 and the lateral station 14. The outer positions AXX 13 and 14 and DXX 14 and 15 are usually not utilized because they fall outside the actual wear zone of the tread.

The 12 circumferential and three lateral stations were marked on the tread by crosshairs scratched lightly into a thin coat of white paint applied to the groove bases, as indicated in Figure 12 and also in Figures 25-29. No difficulties and only very small errors were encountered in placing the device repeatedly in the same position.

Before and after each tread measurement, the device was checked on a specially built calibration fixture, Figure 13. The stability of the four channels proved to be excellent. Figure 14 shows that long-term and short-term fluctuations were small, of the order of 1/2 mil. In the analysis of single wear runs, the long-term fluctuations could be completely ignored; and the short-term fluctuations, reduced to negligible levels by proper averaging.

The device was integrated into the TIRF computer system so that wear data could be easily recorded and processed. Table 4 shows the computer output

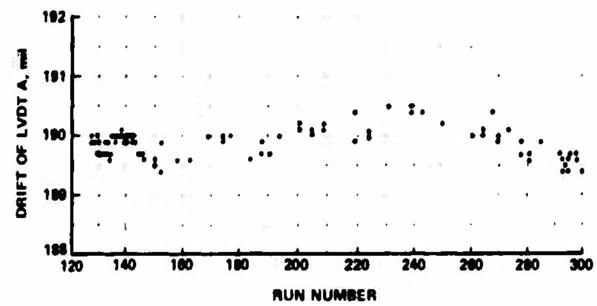


Figure 14. Drift of LVDT A.

Figure 12. Identification of angular and lateral stations.

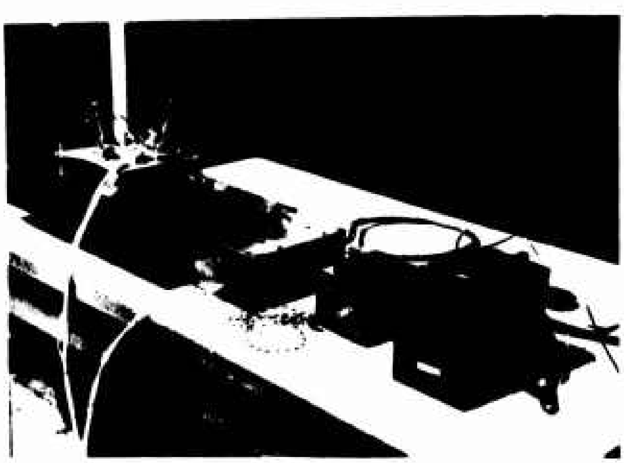


Figure 13. Calibration fixture for wear measuring device.

Table 4
EXAMPLE OF COMPUTER PRINT-OUT OF WEAR MEASUREMENTS FOR A GIVEN LATERAL STATION (HERE, 14).

TACOM - WEAR

Circumferential stations	WEAR A (LVDT A) BASELINE RUN 103 (tread height measurement before wear run, in mil)	COMPARISON RUN 110 (tread height measurements after wear run, in mil)	(AVG= -5.4) (average of 12 differences) DIFFERENCE (103 -110) (difference in tread height, in mil)	WEAR B BASELINE RUN 103	COMPARISON RUN 110	(AVG= -5.6) DIFFERENCE (103 -110)
1	-184.1	-177.0	-7.0	-165.1	-162.3	-2.8
2	-183.4	-176.[illegible]	-6.[illegible]	-16[illegible].5	-161.9	-4.6
3	-188.6	-181.1	-7.5	-164.7	-159.0	-5.7
4	-190.2	-186.8	-3.4	-164.1	-159.6	-4.5
5	-178.6	-173.[illegible]	-4.8	-161.4	-155.4	-5.9
6	-176.[illegible]	-171.[illegible]	-5.0	-16[illegible].[illegible]	-158.2	-4.2
7	-189.6	-186.0	-3.6	-165.8	-160.9	-5.8
8	-189.5	-180.[illegible]	-8.[illegible]	-166.3	-159.5	-6.8
9	-186.4	-180.8	-5.6	-164.9	-157.9	-7.0
10	-183.6	-178.9	-4.[illegible]	-168.9	-162.0	-6.0
11	-186.0	-182.2	-3.[illegible]	-164.1	-159.0	-5.1
12	-180.2	-176.1	-4.1	-166.2	-158.6	-7.5

	WEAR C BASELINE RUN 103	COMPARISON RUN 110	(AVG= -5.9) DIFFERENCE (103 -110)	WEAR D BASELINE RUN 103	COMPARISON RUN 110	(AVG= -4.5) DIFFERENCE (103 -110)
1	-171.1	-162.7	-8.3	-201.0	-199.4	-1.5
2	-168.9	-161.5	-7.3	-186.1	-183.1	-2.9
3	-170.9	-163.6	-7.3	-181.9	-178.6	-3.2
4	-171.9	-166.9	-5.0	-180.8	-177.4	-3.4
5	-180.0	-173.5	-6.4	-196.6	-190.5	-6.1
6	-170.1	-164.3	-5.7	-198.7	-195.0	-3.6
7	-164.6	-161.3	-3.2	-189.9	-184.9	-5.0
8	-163.0	-154.9	-8.0	-183.1	-178.1	-5.0
9	-171.8	-164.8	-6.9	-184.4	-179.6	-4.7
10	-171.1	-165.4	-5.6	-193.2	-187.5	-5.6
11	-162.6	-159.1	-3.5	-190.1	-183.1	-6.9
12	-162.0	-15[illegible].7	-[illegible].2	-193.6	-193.5	-6.1

TACOM - WEAR

** STANDARD DEVIATION **

COMPARISON RUNS #103- #110

WEAR POINT	STANDARD DEVIATION (standard deviation of single measurement, in mil)
-A-	1.72
-B-	1.39
-C-	1.60
-D-	1.57

of a typical wear run. For each of the 12 circumferential stations (of a given lateral station), and each of the four LVDT's A-D, the differences in tread heights measured before and after a wear run are printed out. Furthermore, the 12 differences of each LVDT are averaged and printed out together with the standard deviation (of single measurement). Hence, for each wear run, 12 averages (four LVDT's and three lateral positions) with 12 standard deviations are generated, indicating the wear of 12 meridians around the tire.

The procedure of measuring wear was as follows: the tire tread was first thoroughly cleaned and then marked for the wear measuring device. Following this, the tire was inflated and suspended for a few hours on a rack in an air-conditioned room. In this way heat spotting and unequal temperature distribution were avoided. Then, the device, which had been calibrated shortly before, was placed on the designated 36 locations around and across the tire tread, and 144 measurements of the tread height were recorded, (Figure 15). This took about 10 to 15 minutes. Figure 16 shows a close-up of the device in position. The tire was then mounted on TIRF (Figure 17) and run under the specified conditions of speed, slip angle, load, time, etc. After the run, the tire was allowed to cool, and second tread height readings were taken at the same positions of the prewear readings. Finally, the data were printed out, as indicated in Table 4.

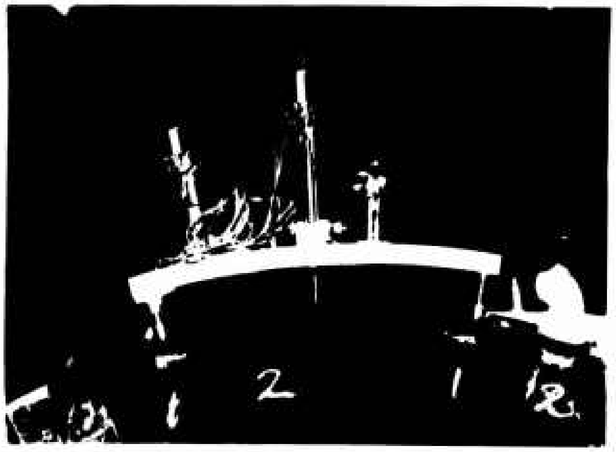


Figure 16. Wear measuring device in position.

Figure 17. Test tire mounted on tirf.

EXPERIMENTAL ERRORS

The tread heights measured before and after a wear run and their differences indicate not only the actual wear losses but a number of experimental errors as well. Our tests revealed six different sources of error; they are listed in Table 5.

Figure 15. Tread height measurements.

Table 5
SOURCES OF MEASUREMENT ERRORS

- RANDOM SOURCES
  - INSTRUMENTATION SYSTEM
  - WEAR FLUCTUATIONS (AROUND TIRE)
  - PLACEMENT OF WEAR MEASURING DEVICE ON DESIGNATED TREAD LOCATION (BEFORE AND AFTER A WEAR RUN)
- VISCO-ELASTIC-PLASTIC TREAD RUBBER PROPERTIES
  - SINKAGE OF WEAR MEASURING DEVICE INTO TREAD RUBBER
  - CREEP OF TREAD RUBBER AFTER TEST RUN
  - RESIDUAL RUBBER DEFORMATIONS
- TIRE BREAK-IN (PERMANENT CHANGE OF TIRE SHAPE)
- TIRE TEMPERATURE
  - THERMAL EXPANSION OF TREAD RUBBER (NEGLIGIBLE)
  - THERMAL DEFORMATION OF TIRE
- WEAR "DUST"
- WEAR HISTORY

1. Random errors are caused by the instrumentation system, by wear fluctuations around the tire, and by slight misplacements of the wear measuring device during the measurement process. Table 6 shows that the mean values of the instrumentation and the placement errors are (nearly) zero; they are no biased. Hence, the accuracy of a wear measurement can be expressed in terms of the standard deviation. The standard deviation of the wear fluctuations around the tire is much larger than the standard deviations of both the instrumentation system and the placement process. Table 6 shows that with 96 measurement points around the tire (per wear test), the instrumentation system error is only 0.02 mil; and the placement error, 0.04 mil. The combined errors of all three sources amount to 0.16 mil, an error much smaller than the accuracy of 1 mil specified as desirable at the outset of this investigation.

2. Errors caused by the visco-elastic-plastic properties of the tread rubber are of a different kind than random errors; they introduce systematic offsets present in each measurement. Hence, they cannot be reduced by repetitions; their effects can be suppressed only by suitable modifications of the measurement technique.

We identified three sources of errors caused by visco-elastic-plastic rubber properties (Table 5): sinkage, creep, and residual deformation. Sinkage is characterized in Figure 18. As soon as the tread rubber is loaded by the wear meter, the device begins to sink into the rubber -- initially, at a rate of 0.3 mil/min; later, at a much slower rate of 0.1 mil/hour. Hence, if the measurement process can be kept within, say, 10 seconds, the sinkage error will be very small.

The visco-elastic behavior of a tire also accounts for the phenomenon of creep: after a run is completed and the load is removed, the tire returns slowly to its original shape. In Figure 19, a tire was loaded by 800 lb for one hour. Immediately after load release, continuous tread height measurements were taken. The initial compression of the tire tread was about 11 mils. The tread returned slowly toward its original height, first at a rate of 0.9 mil/min, later at 0.1 mil/hour. After 20 hours, the height was still off the original height by 2 mils.

The effects of creep on the measurement accuracy can be effectively reduced by introducing a waiting period of about one day after a wear run is completed. The effect of residual rubber deformation is unknown at this time and has to be explored further.

3. Tire break-in has a significant effect on wear measurements. It appears that during the first fifty miles or so of tire operation, certain internal bondages and stresses caused by the manufacturing process are relaxed, and the tire settles into a more permanent shape. Table 7

Table 6
RANDOM (UNBIASED) ERRORS

- INSTRUMENTATION SYSTEM ERROR (CALIBRATION)
  - MEAN 0.008 mil ≈ 0
  - STANDARD DEVIATION 0.2 mil
  - STANDARD DEVIATION OF MEAN (96 POINTS) — 0.02 mil
- ERROR DUE TO WEAR FLUCTUATIONS AROUND TIRE
  - STANDARD DEVIATION 1.5 mil
  - STANDARD DEVIATION OF MEAN (96 POINTS) — 0.15 mil
- ERROR DUE TO REPETITIVE PLACEMENT OF WEAR MEASURING DEVICE
  - MEAN 0.06 mil (≈ 0)
  - STANDARD DEVIATION 0.4 mil
  - STANDARD DEVIATION OF MEAN (96 POINTS) — 0.04 mil

TOTAL (RANDOM) ERROR 0.16 mil

$$\left(= \sqrt{0.02^2 + 0.15^2 + 0.04^2} \right)$$

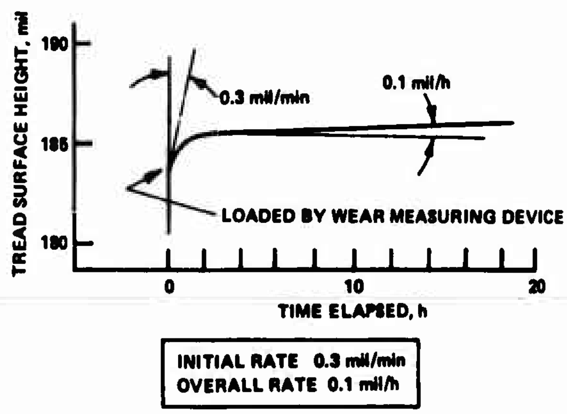


Figure 18. Instrument sinkage error.

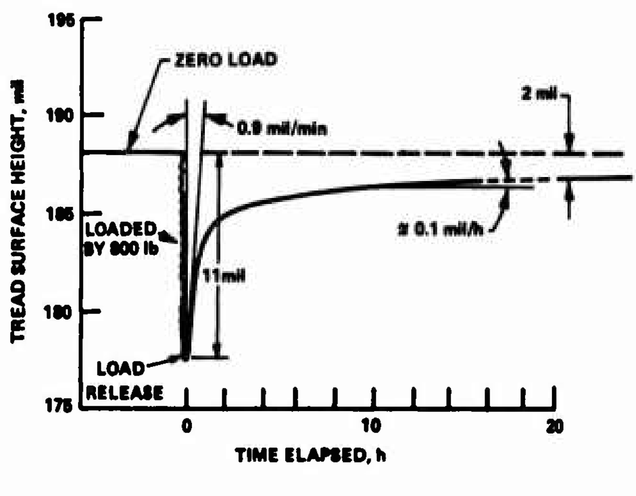


Figure 19. Creep error (after run).

gives an illustration. The first wear runs of new tires showed a "wear" Δh (first) 2.3 to 5.8 times larger than the wear Δh (second) of the second run under identical run conditions. Therefore, the first fifty miles or so of a wear run cannot be utilized for wear measurements; they have to be considered part of the test preparation.

4. Temperature has a distinct effect on the measurement of wear. Figure 20 shows a sequence of tread surface measurements taken before and after a wear run. During the wear run, the tread temperature increased from 70 F to 135 F. A tread surface measurement immediately after the end of the run indicated a growth in tread height of 17 mils, which completely obscured the actual wear effects. As the tire cooled, the tread height decreased. When the pre-run temperature of 70 F was reached, the tread had contracted beyond the initial height by 2 mils -- the actual wear. Figure 21 shows that about four hours are needed after a run to stabilize the tread dimensions. Consequently, after each wear run, a cooling period of about six hours had to be introduced.

It later became obvious, however, that soaking alone was not sufficient to achieve consistent results. Figure 22 shows wear rates measured repeatedly on the same tire under identical wear conditions. Although soak periods of at least 24 hours were observed, we found rather large fluctuations among the wear rates measured after the first break-in run. Further investigations revealed that these irregularities were caused by rather small temperature changes that occurred in the soak periods between pre-run and post-run measurements. In Figure 22, the higher rates are associated with a drop in temperature; the lower rates, with an increase. The temperature changes were small, of the order of a few degrees F. We knew, of course, that rubber would thermally expand and shrink, but we estimated these effects to be very small. It was, therefore, surprising to learn that one or two degrees F would change the shape of the tread rather drastically. A possible explanation is that under the influence

Table 7
BREAK-IN ERROR

RUN CONDITIONS	BREAK-IN DISTANCE MILES	Δh (FIRST RUN) / Δh (SECOND RUN)
α = 0°	180	5.8
α = ±0.5°	30	4.8
α = ±1.0°	60	4.2
T = +100 ft lb	60	5.7
T = -100 ft lb	60	2.3

Δh IS THE DIFFERENCE OF TREAD SURFACE MEASUREMENTS TAKEN BEFORE AND AFTER A WEAR RUN

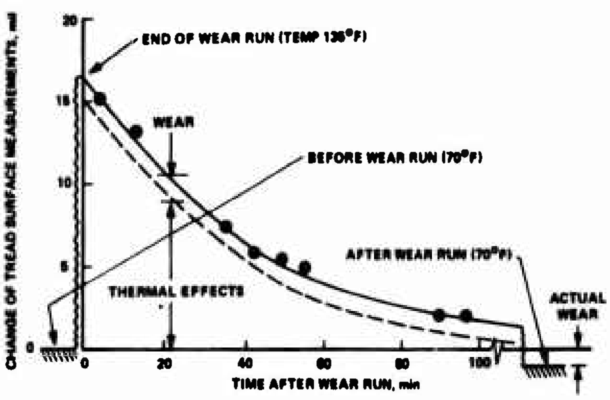


Figure 20. Temperature effects on tread surface measurements.

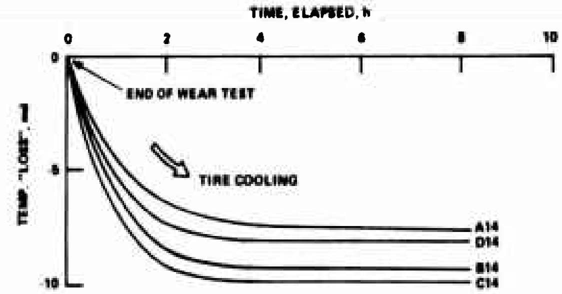


Figure 21. Effect of tire cooling on tread surface measurements (wear measuring deveic stationary).

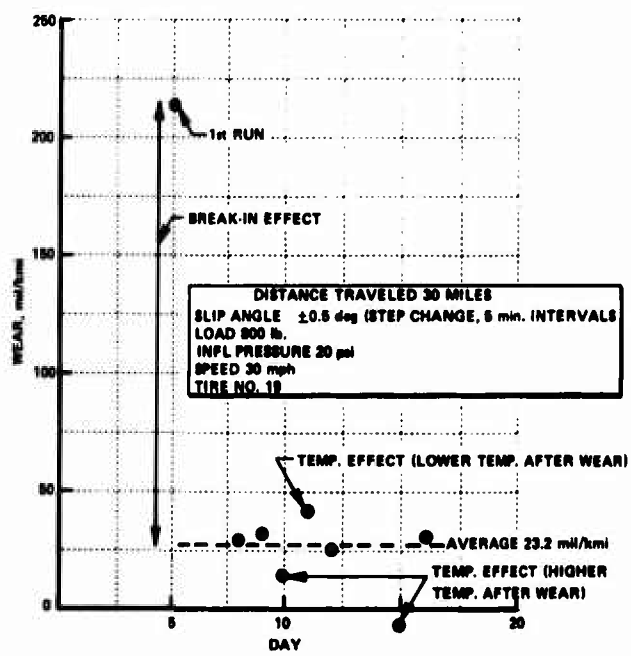


Figure 22. Repeatability of wear results.

of temperature the tire cords contract or expand and in this way deform the tread significantly, as indicated in Figure 23. We then systematically heated and cooled a tire by a few degrees and measured the changes in tread height. Figure 24 shows that the average change of tread height with temperature was about 0.5 mil/deg F. As a consequence of this rather large temperature effect, it appears necessary to control the temperature of the soak area within narrow limits, depending on the accuracy required.

5. During a wear run, small rubber particles accumulated on the tread surface; they had tc be brushed off to avoid measurement errors.

6. Different wear conditions generate different wear patterns. Tested under free-rolling conditions, for instance, a tire develops parallel wear bands at both sides of the center ridge (Figure 25). Under cornering conditions, with the slip angle varying sinusoidally, the wear is more evenly distributed across the tread surface (Figure 26). However, parallel ridges may develop in certain areas. These ridges have been described

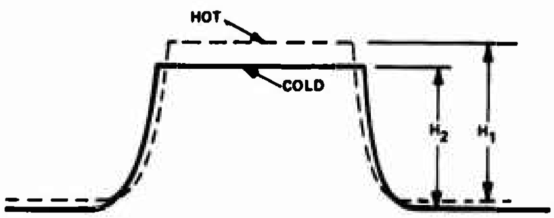


Figure 23. Thermal tire deformation (conjectured).

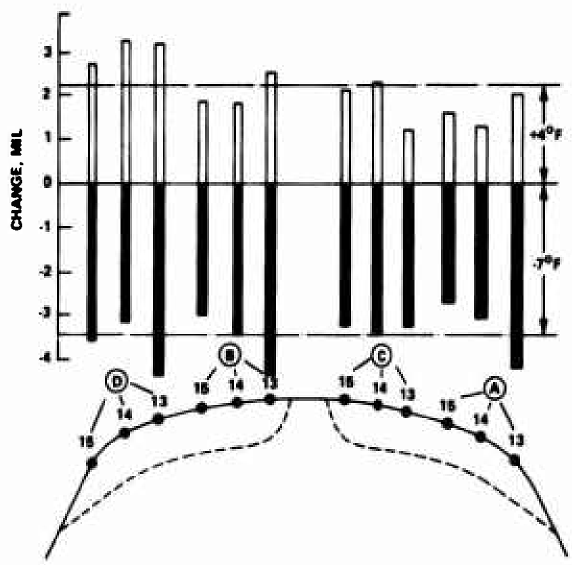


Figure 24. Change of tread surface measurements at points A13-D15 with tire temperature, at a constant inflation pressure (20 psi) $\Delta h \approx 0.5$ mil/°F.

SLIP ANGLE	0°
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	30 mph
DISTANCE TRAVELED	90 miles

Figure 25. Wear pattern of free rolling tire.

SLIP ANGLE	±1° (sinusoidal; 0.1 Hz)
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	60 mph
DISTANCE TRAVELED	240 miles
TIRE NO.	28

Figure 26. Wear pattern of cornering tire.

by Schallamach [9] in detail and are, therefore, often called Schallamach waves. Their intensity depends on many factors such as coarseness of the road surface, stiffness of the rubber, and direction of relative motion between tread and road. Very coarse Schallamach waves were observed when the tire was subjected to driving (Figure 27). Under braking, step wear developed between the center ridge and the tread logs (Figure 28); also, the trailing edges of the logs showed considerably more wear than the leading edges. Under combined braking and cornering, additional Schallamach waves could be observed on the center ridge (Figure 29). In Appendix B, some footprints of worn tires are presented on which the various wear patterns can again be identified.

From this, it is obvious that the topography of the wear surface depends strongly on the wear conditions imposed. It also follows that the amount of rubber abraded under given wear conditions depends on the wear history. For instance, the wear obtained from a cornering test that was preceded by, say, a free-rolling test is different from the wear of the same cornering test obtained from a new tire never wear-tested before. Therefore, to secure consistent results, each wear test should be started from a new tire.

Table 8 lists again the six major sources of errors and the means to eliminate or reduce them, as discussed.

TEST PROGRAM

The test program encompassed four common types of tire operation

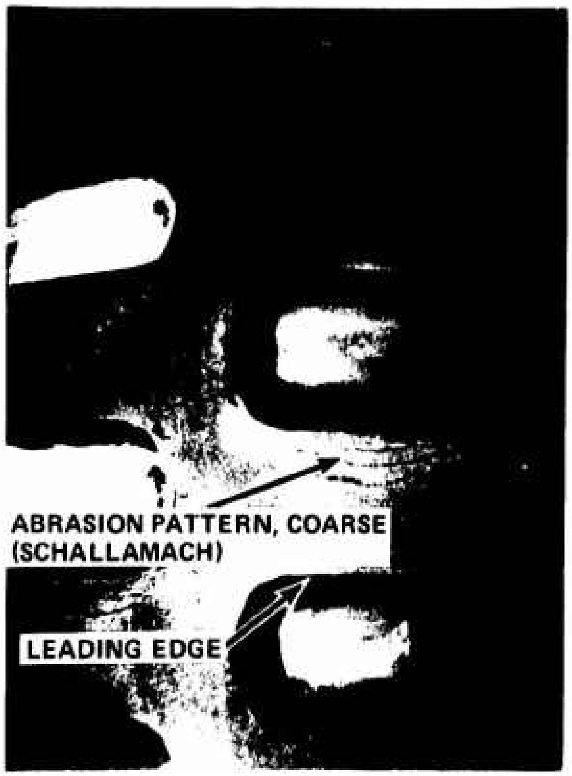
Straight free-rolling

Cornering under free-rolling

Straight driving and braking

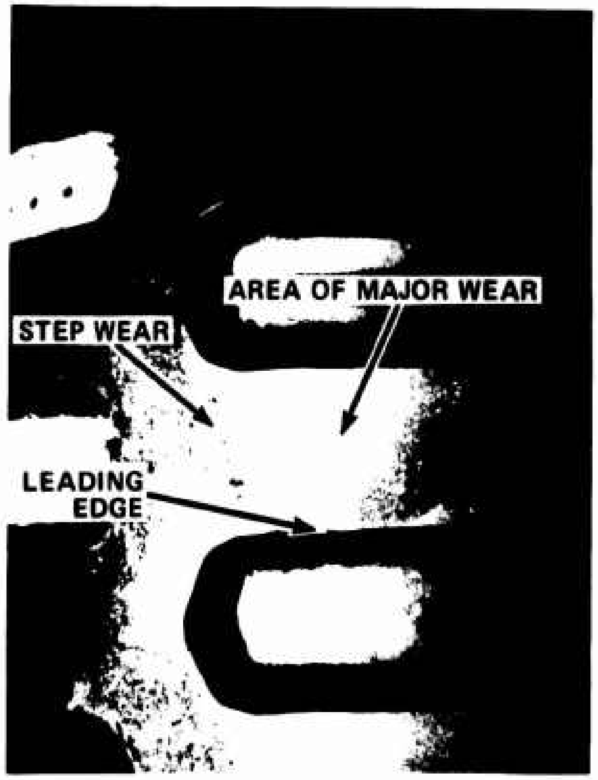
Cornering under driving and braking

In addition, the influence of load, speed, and tire pressure on wear were investigated. All



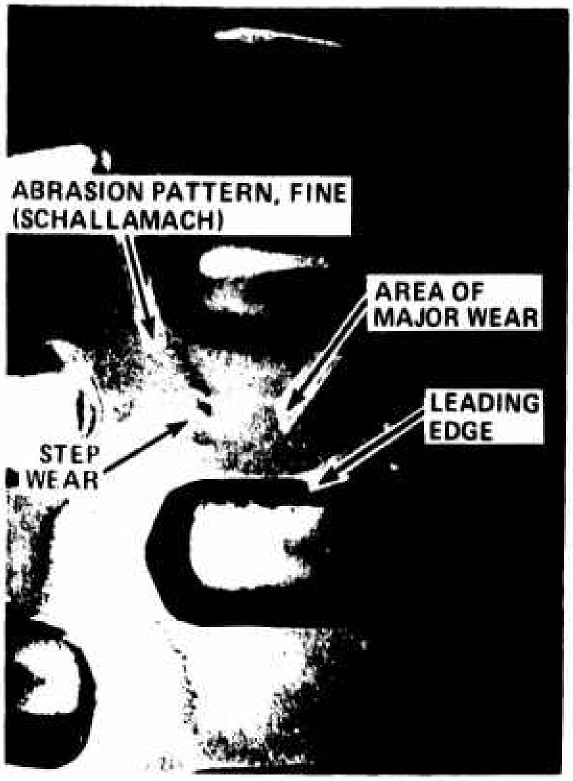
TORQUE	+100 ft/lb
SLIP ANGLE	0°
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	60 mph
DISTANCE TRAVELED	240 miles
TIRE NO.	30

Figure 27. Wear pattern of driving tire.



TORQUE	-100 ft/lb
SLIP ANGLE	0°
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	60 mph
DISTANCE TRAVELED	240 miles
TIRE NO.	29

Figure 28. Wear pattern of braking tire.



TORQUE	-100 ft/lb
SLIP ANGLE	±1° (sinusoidal; 0.1 Hz)
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	60 mph
DISTANCE TRAVELED	240 miles
TIRE NO.	32

Figure 29. Wear pattern of braking/cornering tire.

Table 8
ELIMINATION OR REDUCTION OF MEASUREMENT ERRORS

- RANDOM SOURCES
  - LARGE NUMBER OF WEAR MEASUREMENT POINTS AROUND TIRE
- VISCO-ELASTIC-PLASTIC TREAD RUBBER PROPERTIES
  - LIGHT-WEIGHT PROBE
  - RAPID MEASUREMENTS
  - 24 h WAITING PERIOD AFTER TEST BEFORE TAKING MEASUREMENTS
- TIRE BREAK-IN
  - 30 MIN BREAK-IN UNDER TEST CONDITIONS
- TIRE TEMPERATURE
  - SAME TIRE TEMPERATURE FOR MEASUREMENTS BEFORE AND AFTER WEAR RUN
- WEAR DUST
  - BRUSHING
- WEAR HISTORY
  - NEW TIRE FOR EACH NEW TEST CONDITION

tests were performed on 7.00-16 LW NDCC military tires. Under normal military service conditions, this tire experiences loads between 765 and 1035 lb at pressures between 20 psi and 25 psi. The operating speed does not surpass 50 mph.

To keep the test conditions in reasonable agreement with actual service conditions, it was decided to vary the

load between 300 lb and 1200 lb

inflation pressure between 16 psi and 24 psi

slip angle between ±2 degrees

torque between +100 ft-lb (driving) and -100 ft-lb (braking)

The torque of ±100 ft-lb is associated with low longitudinal slip values of about ±0.6 percent. Hence, the ranges of both α and s covered in this program are basically in agreement with the ranges called out in Table 1 for normal driving severity.

To simulate actual driving conditions to some degree, and to avoid asymmetrical wear, the slip angle was varied periodically during testing, either sinusoidally or stepwise. In both cases the frequency was low, between 1/10 (sinusoidal change) and 1/600 Hz (step change). The table in Appendix A gives an overview of all tests run. Note that the first runs were all experimental runs to check out the equipment and to develop a viable test technique.

The test procedure was developed in context with the results of the error analysis, described in the Experimental Errors section. Accordingly, for each test, a new tire was used. The tread surface was thoroughly cleaned and carefully marked for the wear measuring device. The tire was then inflated and run on TIRF for 30 minutes under test conditions. After this break-in run, the tire was soaked for at least 12 hours in an air-conditioned room before the tread height was measured at the designated locations and recorded on magnetic tape. Following this, the actual wear run was performed. After the run, the tire was soaked again for at least 12 hours in the air-conditioned room, and measurements were taken and recorded. Finally, the differences in tread height and their standard deviation were computed and printed out.

TEST RESULTS AND COMPARISON WITH FIELD TESTS

The test results describe the influence of load, inflation pressure, slip angle, and braking and driving on wear.

Two Mansfield tires were run at 800-lb and 1200-lb load under otherwise identical test conditions. The wear results are plotted in Figure 30. They suggest that for the tires tested, wear increases proportionally with load.

In Figure 31, wear is plotted for three Mansfield tires with different inflation pressures. The load was kept at 800 lb (the design load for 20 psi). Wear appears to increase rapidly at inflation pressures lower or higher than the design pressure at design load.

Figure 32 depicts wear data measured as a function of slip angle for a number of Mansfield and Firestone tires. During wear runs, the slip angle was alternated stepwise between $\pm\alpha$ max in five-minute intervals, to avoid asymmetrical wear. Wear is strongly dependent on slip angle; the TIRF data in Figure 32 plotted on semi-log paper indicate an exponential relation of the type

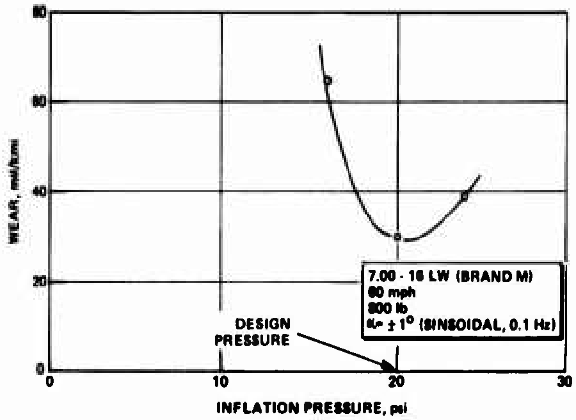


Figure 30. Wear versus tire load.

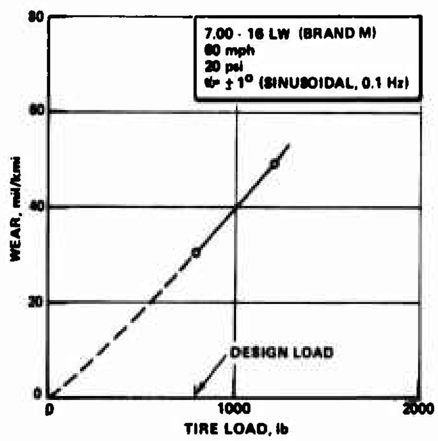


Figure 31. Wear versus inflation pressure.

$$w = a e^{b\alpha}$$

For comparison, the road data (cornering) of Reference 4 (plotted in Figure 4) are superposed; they follow the same relation -- a confirmation of our contention that TIRF or a similar laboratory machine can indeed be used to simulate road wear performance. Figure 32 indicates that the Mansfield tires are wearing slightly less than the Firestone tires, by about 17 percent.

$$w_F/w_M = 1.2$$

In Figure 33, the results of braking and driving tests are plotted. The tests were performed with

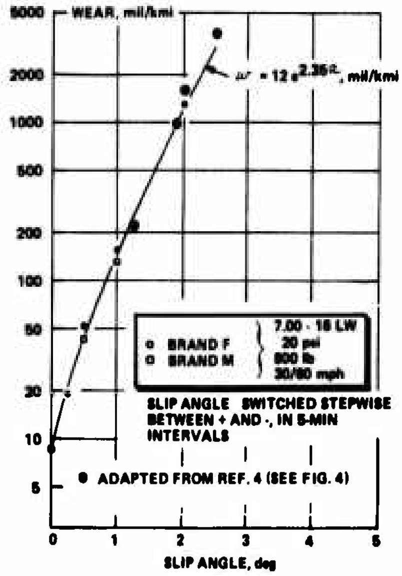


Figure 32. Wear versus slip angle.

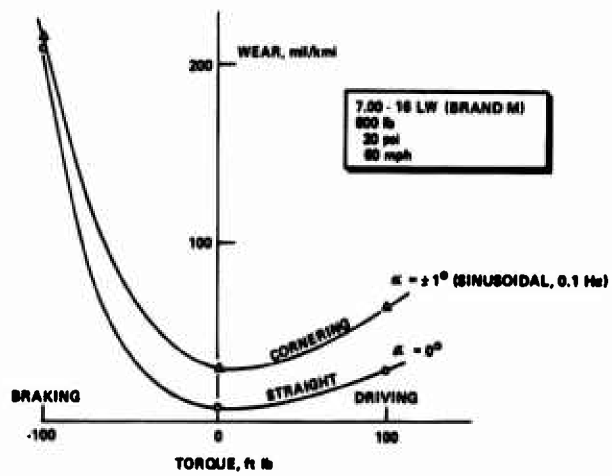


Figure 33. Wear versus torque.

and without simultaneously cornering the tire. In both cases, braking losses are much higher than driving losses -- a consequence of the fact that the displacements of tread elements in the contact area of a braked tire are much larger than those of a driven tire. According to Veith [2], the frictionally dissipated energy in the contact patch of a braked tire is 2.4 times larger than the energy dissipated in the patch of a driven tire, for the same absolute torque of 180 ft-lb. Here, the ratio is even larger -- 3.4 for the cornering tire, and 7 for the straight-rolling tire, perhaps a consequence of the coarse cross-country tread pattern. The cornering-driving tire experiences higher wear than the straight-driving tire, as expected. The wear values of the cornering-braking and the straight-braking tires, however, are nearly equal, for reasons unknown at this time.

Direct comparisons of the wear results generated in this program with road results are frustrated by the fact that road tests are usually performed under random variations of slip angle, load, speed, etc. Indirect comparisons, however, are possible in two ways.

1. The tread surface exposed to different wear conditions assumes different microscopic wear patterns. Figures 34 through 39 are scanning electron microscope (SEM) tread surface photos of Mansfield tires tested on TIRF under various wear conditions. Most of the depicted tread surfaces exhibit particular Schallamach wave patterns, depending on the wear condition imposed. For comparison with TIRF-generated surfaces, a SEM tread surface photo was made of a Mansfield tire that had been in practical use as a rear tire on a jeep (Figure 40). Its wear pattern shows close resemblance to the pattern of the tire tested on TIRF under driving and cornering conditions (Figure 39). We take the similarity between the two patterns as an indirect proof of TIRF's capability to simulate actual road wear conditions.

2. Another indirect comparison between TIRF and road wear data is offered by test data published in Reference 10. In these tests, NDCC military tires, size 7.00-16, were mounted on 1/4-ton trucks, 4 x 4 M 151 A2 (jeep), and tested at various speeds on paved roads, secondary roads, and open terrain. For Mansfield* tires, the following wear data were measured per 600 miles on paved roads (Table 8, Truck No. 3; Reference 10):

Free-rolling	Left Front (770 lb) w = 12 mils; std. dev. 7 mils
Free-rolling	Right Front (770 lb) w = 10 mils; std. dev. 7 mils

*In the report, Mansfield tires were coded by letter W. (Personal communication, Mr. Richard Heinrich, TACOM)

Figure 34. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Tirf
$\alpha = \pm 0.5^{\circ}$ (square wave, 1/600 Hz)
Tire Brand M

Figure 35. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Tirf
$\alpha = \pm 1^{\circ}$ (sinusoidal, 0.1 Hz)
Tire Brand M

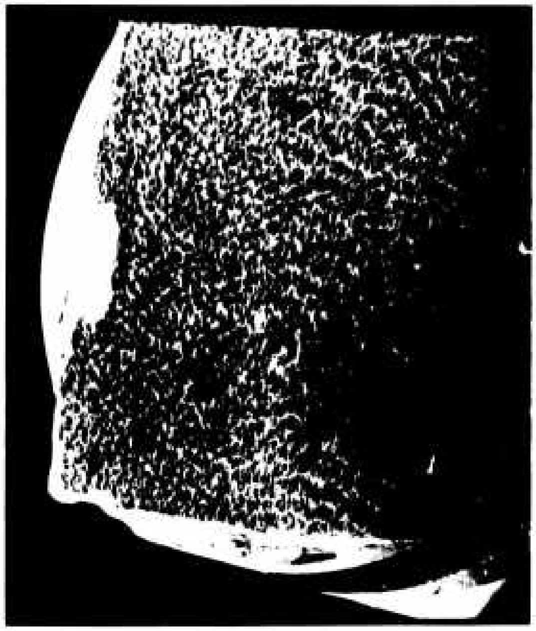


Figure 36. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Tirf
Straight Braking (-100 ft/lb)
Tire Brand M

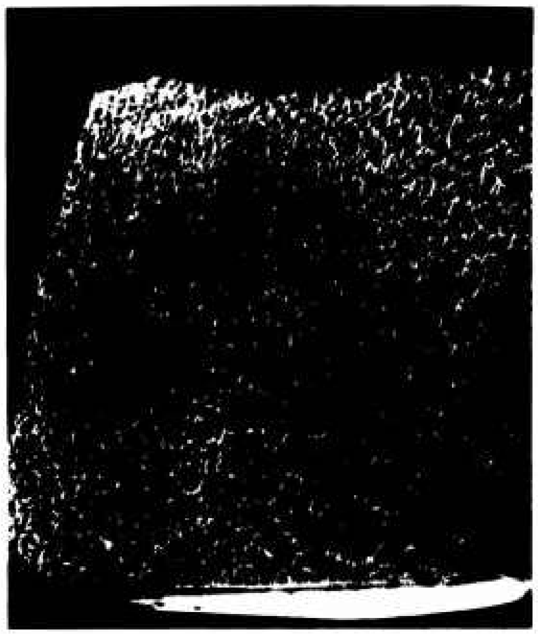


Figure 38. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Tirf
Straight Driving (+100 ft/lb)
Tire Brand M

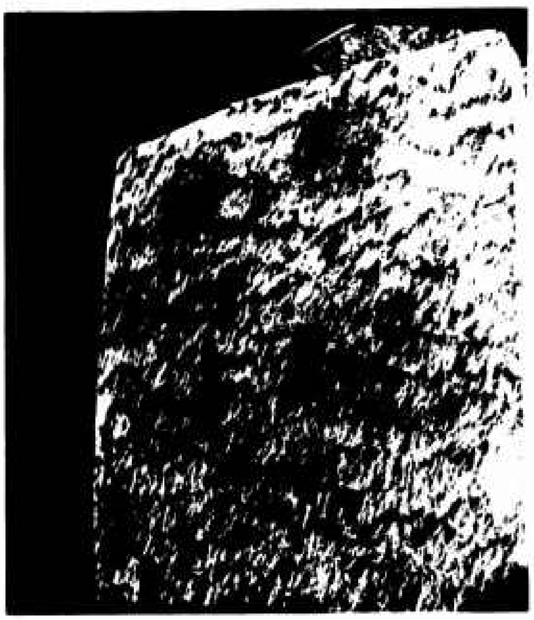


Figure 37. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Tirf
Braking - Cornering (-100 ft/lb)
$\alpha = \pm 1^{\circ}$ (sinusoidal, 0.1 Hz)
Tire Brand M

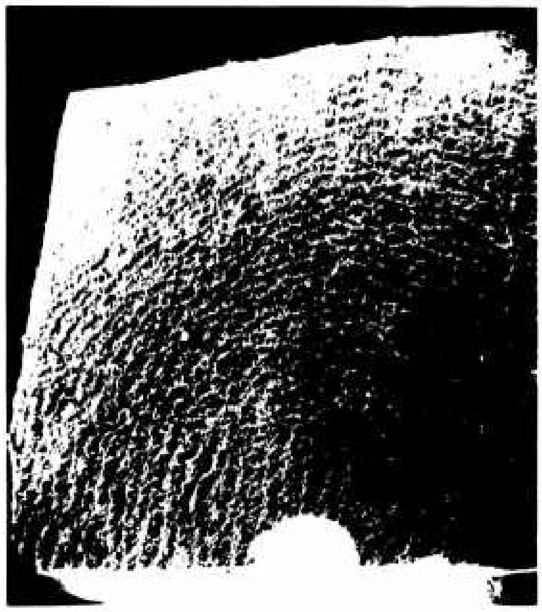


Figure 39. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Tirf
Driving - Cornering (+100 ft/lb)
$\alpha = \pm 1^{\circ}$ (sinusoidal, 0.1 Hz)
Tire Brand M

Figure 40. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Jeep
Field Conditions
Tire Brand M (Rear)

Driven — Left Rear (1043 lb)
w = 58 mils; std. dev. 19 mils

Driven — Right Rear (1043 lb)
w = 63 mils; std. dev. 12 mils

For the free-rolling tires, then, the average wear rate was 18 mils/kmi (std. dev. 12 mils); for the driven tires, it was 101 mils/kmi (std. dev. 26 mils).

To compare these road wear rates with rates measured on TIRF, we first computed the slip angle that produces a wear rate of 18 mils/kmi under front wheel load. Using TIRF data, we found this slip angle to be ±0.6 degree (sinusoidal variation, 0.1 Hz) -- a plausible result (see Table 1). With this angle, we produced an estimate of the rear tire wear under rear wheel load.

Using average numbers for aerodynamic resistance and tire rolling losses, we computed a rear wheel torque of 100 ft-lb. Under pure driving with no braking (slip angle ±0.6 degree), this torque corresponded to a wear rate of 70 mils/kmi. With 17% braking, the wear rate rose to 100 mils/kmi -- the value measured on Yuma Proving Ground.

Of course, the slip angle of ±0.6 degree, the slip angle frequency of 0.1 Hz, the torque of ±100 ft-lb, and the percentages of driving and braking of 83% and 17%, respectively, are all educated guesses of the actual driving conditions of the jeep tested. In view of the many uncertainties, however, the agreement between TIRF and Yuma data must be considered satisfactory.

CONCLUSIONS AND RECOMMENDATIONS

Wear resistance, one of the most important properties of pneumatic tires, has been measured in the past almost exclusively in road tests, either under normal (passenger car) or accelerated conditions (trailers). Both methods have serious drawbacks. A third method that would combine the advantages of the controlled, short-term trailer tests with the real-life wear conditions of passenger car tests was, therefore, highly desirable.

With TIRF, an opportunity was given to develop such a method. TIRF features a flat surface, a large speed range, realistic road surfaces, and the capability to simulate a large variety of wear cycles under tight control of slip angle, load, speed, etc. This program is primarily concerned with the development of an efficient test methodology that would permit the determination of a tire's wear loss after only a few hours' run of normal severity. This objective has been achieved with excellent results.

An electromechanical wear measuring system has been developed with an accuracy of 0.2 mil (st. dev. of single measurement).

A short-duration, wear measuring procedure for normal-driving (low-severity) conditions has been developed including

A tire break-in of 30 minutes under test conditions

Wear runs at controlled slip angle, load, speed, torque, etc., on TIRF with wear durations between 30 minutes and 3 hours

Wear measurements at more than one hundred tread locations at constant tire temperature

Computer storing and processing of wear data

The major sources of experimental errors (due to temperature, tire creep, and nonuniform wear) have been identified and either eliminated or reduced to low noise levels.

A wear program has been performed on 7.00-16 LW military tires under various conditions of inflation pressure, load, speed, slip angle, and driving and braking torque.

The test results indicate that in the range of normal driving (up to 2 degrees slip angle, 1200-lb load, and ±100 ft-lb torque), wear (in mil/kmi) is

An exponential function of slip angle

A linear function of tire load

reaches a minimum at design pressure or 20 psi

is many times higher for braking than for driving

Direct comparisons between TIRF measured and vehicle measured wear data are frustrated by the fact that the wear conditions of vehicle tests are usually varying randomly within rather large ranges. Under these circumstances, indirect comparisons were tried -- with good success. (1) It was noted that the microwear pattern of the tread surface, i.e., the Schallamach waves, observed (under a scanning electron microscope on the tread surface of a tire worn in actual road use was similar to that indicated on an identical tire tested on TIRF under corresponding, simulated road conditions. (2) Road wear data measured by the U. S. Army on the Yuma Proving Ground could be reproduced from TIRF data with the help of estimated wear cycles that presumably had prevailed during road testing. Both results permit the conclusion that short-duration wear data generated on TIRF adequately reflect actual wear conditions on the road. Hence, it can be expected that on TIRF or a similar indoor machine, valid wear data can be generated in a few hours' wear time under normal wear conditions.

With these favorable conclusions, a reliable basis is provided for an expansion of this program. The following steps are suggested:

A wear cycle reflecting average road wear conditions should be devised. The cycle could be either of deterministic or of random nature, or it could contain a combination of deterministic and random elements. For instance, the slip angle could be varied randomly according to a normal distribution, whereas the associated loads could be made dependent on the slip angle.

Noise and uncertainty levels in wear measurements should be reduced further.

The electromechanical wear measuring instrument should be redesigned to accommodate different tread patterns.

A number of tires of different size, construction type, and tread design should be tested and ranked with respect to their wear resistance.

Results from these tests should be correlated to those obtained by TACOM on the same tires.

The results should also be used to specify a simple tire wear machine based on Calspan's flat-bed Simulated Roadway Unit (SRU) concept. SRU's are currently manufactured under a Calspan license and can be readily adapted to wear applications.

QUESTIONS AND ANSWERS

Q: (Mr. Shaver) Are the facilities at your testing facility available to industry and if so, on what basis?
A: Indeed they are available. Just contact us and we will give you a price. The machine is available, and we will do the study for you. This is our business. This machine, by the way, was funded by the major tire manufacturers and by the Government 2-1/2 to 3 years ago and since then we have been doing studies for industry and for the government -- various studies mostly force and moment measurements and wear studies for which this machine is ideal.

Comment: (Vogel) We should add, the machine is available on-site in Buffalo. It weighs a couple of hundred tons so it wouldn't be available in the field.

Q: How do you monitor your temperature? Do you use any infrared radiometers?
A: We have two infrared instruments, and we also have feedback control. One infrare. instrument measures the road temperature, another one looks at the tire surface and tread surfaces and we have an inside probe that measures cavity temperature.
Q: What is the maximum load capacity of the equipment?
A: There are two balances, one for passenger car tires and one for truck tires. With passenger tires we can go up to 12,000 lb altogether, but for passenger we normally go only to 2,000 or 3,000. If we have to go higher, we use a truck balance which we can go up to 12,000, usually it's 8,000 or so.
Q: Is there a written paper available covering what you have talked about?
A: Yes, that is, I have to write a report on this and it will be available in a month or two.

APPENDIX A. TEST SCHEDULE

TACOM TIRE TEST SCHEDULE

	RUN NO. (20-1-)	TIRE NO.	TIRE BRAND	TYPE OF RUN		DATE (1975)
	1	8	FIRESTONE	WEAR CHECK	POSITION 14	10/14/75
	2			WEAR RUN		
	3			WEAR CHECK		
	4			WEAR RUN		
	5			WEAR CHECK		
	6			WEAR RUN		
	7			WEAR CHECK		
	8					10/15/75
	9					
	10					
	11					
	12					
	13					10/16/75
	14					
	15					
	16					
	17					
	18			10 MIN. WEAR RUN		
	19			WEAR CHECK		
	20			WEAR CHECK		
	21			10 MIN. WEAR RUN		
	22			WEAR CHECK		
	23			WEAR CHECK		
	24			10 MIN. WEAR RUN		
	25			WEAR CHECK		
	26			WEAR CHECK		
	27	8	FIRESTONE	10 MIN. WEAR RUN	POSITION 14	10/16/75
	28			WEAR CHECK		
	29			WEAR CHECK		
	30			10 MIN. WEAR RUN		
	31			WEAR CHECK		
	32			WEAR CHECK		
	33			10 MIN. WEAR RUN		
	34			WEAR CHECK		
	35			WEAR CHECK		
	36			WEAR CHECK		10/17/75
	37			WEAR CHECK		
	38					
	39					
	40					
	41					
	42			1 HR. WEAR RUN		
	43			WEAR CHECK	POSITION 14	
	44					
	45					
	46					
	47					
	48					
	49					
	50					
	51					10/20/75
	52					
	53	8	FIRESTONE	WEAR CHECK	POSITION 14	10/24/75
	54			INSTRUMENTATION CHECK		
	55					
	56					
	57					
	58					
	59					
WEAR RUN	60			1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.		11/5/75
	61	7		½ HR. $\theta = \pm 1^\circ$ EVERY 5 MIN.		
	62			WEAR CHECK		
	63	8		WEAR CHECK		
WEAR RUN	64	8		10 MIN. $\theta = \pm 5^\circ$ EVERY 5 MIN.		
	65	6		WEAR CHECK		
WEAR RUN	66			30 MIN. $\theta = \pm 1^\circ$ EVERY 5 MIN.		
	67	7		WEAR CHECK		
WEAR RUN	68			1 HR. $\theta = \pm ½^\circ$ EVERY 5 MIN.		
	69	8		10 MIN. $\theta \pm 5^\circ$ EVERY 5 MIN.		
	70			WEAR CHECK		
	71	7		WEAR CHECK		
	72	8		WEAR CHECK		
WEAR RUN	73	6		1 HR. $\theta = 0$ DRIVING $T = +100$ FT. LB.		
	74	7		½ HR. $\theta = \pm 1^\circ$ EVERY 2½ MIN.		
	75	8		5 MIN. $\theta = \pm 5^\circ$ EVERY 2½ MIN.		
	76	9		WEAR CHECK		11/7/75
	77			FLAT PLATE CREEP TEST (10 HR.)		11/6/75
	78	8		TIRE CREEP TEST (10 HR.)		11/6/75
	79	9	FIRESTONE	1 HR. $\theta = \pm ½^\circ$ EVERY 5 MIN.	POSITION 14	11/10/75
	80	6		WEAR CHECK		
	81	8		5 MIN. $\theta = \pm 5^\circ$ EVERY 2½ MIN.		
	82	10		½ HR. $\theta = \pm 1^\circ$ EVERY 2½ MIN.		
	83	7		WEAR CHECK		
	84	11		1 HR. $\theta = \pm ½^\circ$ EVERY 5 MIN.		
	85			10 HR. CREEP TEST		
	86			MANUAL 5 MIN. CREEP TEST		11/11/75
	87			MANUAL 5 MIN. CREEP TEST		
	88			BATTERY 5 MIN. CREEP TEST		
	89			WEAR CHECK		
	90	8				
	91	8				
	92	10				
	93			½ HR. $\theta = \pm 1^\circ$ EVERY 2½ MIN.		
	94	9		½ HR. $\theta = \pm ½^\circ$ EVERY 2½ MIN.		
	95			½ HR. CREEP TEST		
	96	14		WEAR CHECK; WEAR RUN $\theta = \pm 5^\circ$ 1 HR.		11/12/75
	97	11		$\theta = \pm ½^\circ$ 2 HR.		
	98	12		$\theta = \pm 5^\circ$ 2 MIN.		
	99	14		$\theta = \pm 5^\circ$ 1 HR.		11/13/75
	100			$\theta = \pm 5^\circ$ 1 HR.		
	101	6		$T = 240$ FT. LB. ½ HR.		
	102	13		$\theta = 0$ 2 HR.		
	103	8		$T = 60$ FT. LB. 1 HR.		
	104	14		WEAR CHECK		

TACOM TIRE TEST SCHEDULE

	RUN NO. (65-1-)	TIRE NO.	TIRE BRAND	TYPE OF RUN		DATE (1975)
	105	12	FIRESTONE	WEAR CHECK	POSITION 14	11/13/75
	106	14				
	107	11				
	108	9				
	109	10				
	110	8				
	111	13				11/14/75
	112			INSTRUMENTATION CHECK		12/4/75
	113			LVDT CHECK		
	114					
	115					
	116					
	117					
	118					
	119	10	MANSFIELD			
	120					
	121					
	122			5 MIN. DEFLECTION CHECK		
	123			½ HR. DEFLECTION CHECK		
	124			½ HR. DEFLECTION CHECK		
	125			½ Hr. FILTER LAG CHECK		
	126			½ Hr. FILTER LAG CHECK		
	127			WEAR CHECK		12/5/75
	128					
	129					
	130				POSITION 13	
	131	10	MANSFIELD	WEAR CHECK	POSITION 15	12/5/75
WEAR RUN				1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.		
	132	20		WEAR CHECK	POSITION 13	
	133				POSITION 14	
	134				POSITION 15	
	135	21			POSITION 13	
WEAR RUN		20		1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.		
	136	21		WEAR CHECK	POSITION 14	
	137				POSITION 15	
WEAR RUN				1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.		
	138	20		WEAR CHECK	POSITION 13	
	139				POSITION 14	
	140				POSITION 15	
WEAR RUN				1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.		
	141	20		WEAR CHECK	POSITION 13	
	142				POSITION 14	
	143				POSITION 15	
WEAR RUN				3 HRS. STRAIGHT AHEAD		12/8/75
	144	19		WEAR CHECK	POSITION 13	
	145				POSITION 14	
	146				POSITION 15	
	147	20			POSITION 13	
	148				POSITION 14	
	149				POSITION 15	
	150	19			POSITION 13	
	151				POSITION 14	
	152	10	MANSFIELD	WEAR CHECK	POSITION 15	12/8/75
	153			RE CHECK	POSITION 14	
WEAR RUN				1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.		
	154	20		WEAR CHECK	POSITION 13	
	155				POSITION 14	
	156				POSITION 15	
	157	24			POSITION 13	
	158				POSITION 14	
	159				POSITION 15	
WEAR RUN				½ HR. $\theta = \pm 1^\circ$ EVERY 5 MIN.		
	160	20		WEAR CHECK	POSITION 13	
	161				POSITION 14	
	162				POSITION 15	
	163				POSITION 13	12/9/75
	164				POSITION 14	
	165				POSITION 15	
	166	20			POSITION 13	
	167				POSITION 14	
	168				POSITION 15	
WEAR RUN		10		1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.		
	169	23		WEAR CHECK	POSITION 13	
	170				POSITION 14	
	171				POSITION 15	
	172	24			POSITION 13	
	173				POSITION 14	
	174				POSITION 15	
WEAR RUN		24	MANSFIELD	½ HR. $\theta = \pm 1^\circ$ EVERY 5 MIN.		12/9/75
	175	21		WEAR CHECK	POSITION 13	
	176				POSITION 14	
	177				POSITION 15	
	178	22			POSITION 13	
	179				POSITION 14	
	180				POSITION 15	
	181	23			POSITION 13	
	182				POSITION 14	
	183				POSITION 11	
WEAR RUN		20		1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.		12/10/75
	184			WEAR CHECK	POSITION 13	
	185				POSITION 14	
	186				POSITION 15	
	187				POSITION 13	
	188				POSITION 14	
	189				POSITION 15	
WEAR RUN		20		3 HRS. STRAIGHT AHEAD		
	190	25		WEAR CHECK	POSITION 13	
	191				POSITION 14	
	192				POSITION 15	
	193	27			POSITION 13	
	194				POSITION 14	
	195				POSITION 15	
	196				POSITION 13	
	197				POSITION 14	

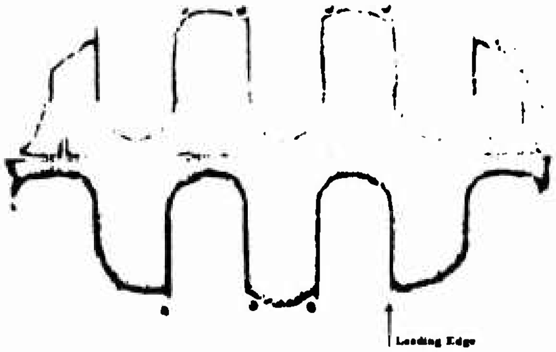
TACOM TIRE TEST SCHEDULE

RUN NO. (20-1)	TIRE NO.	TIRE BRAND	TYPE OF RUN	DATE (1975)
198	20	MANSFIELD	WEAR CHECK POSITION 15	12/10/75
WEAR RUN	19		1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN	
199	20		WEAR CHECK POSITION 13	
200			POSITION 14	
201			POSITION 15	
WEAR RUN	21		1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN	
202	20		WEAR CHECK POSITION 13	
203			POSITION 14	
204			POSITION 15	
WEAR RUN	22		1 HR. $\theta \pm 5^\circ$ EVERY 5 MIN.	12/11/75
205	19		WEAR CHECK POSITION 13	
206			POSITION 14	
207			POSITION 15	
208	21		POSITION 13	
209			POSITION 14	
210			POSITION 15	
211	22		POSITION 13	
212			POSITION 14	
213			POSITION 15	
214	20		½ HR. CREEP TEST	
215			PROBE "D" CHECK	12/12/75
WEAR RUN	19		1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.	
216	22		WEAR CHECK POSITION 13	
217			POSITION 14	
218			POSITION 15	
WEAR RUN			1 HR. $\theta \pm 5$ EVERY 5 MIN	
219	20	MANSFIELD	WEAR CHECK POSITION 13	12/12/75
220			POSITION 14	
221			POSITION 15	
222	19		POSITION 13	12/16/75
223			POSITION 14	
224			POSITION 15	
WEAR RUN	25		1 HR. $\theta = \pm 1^\circ$ SINUSOIDAL	
225	31		WEAR CHECK POSITION 13	
226			POSITION 14	
227			POSITION 15	
WEAR RUN	19		1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN.	
WEAR RUN	25		1 HR. $\theta = \pm 1^\circ$ SINUSOIDAL	
WEAR RUN	27		1 HR. $\theta = \pm 1^\circ$ SINUSOIDAL	
WEAR RUN	28		1 HR. $\theta = \pm 1^\circ$ SINUSOIDAL	
228	20		PRE LOAD - CREEP TEST	
229	19		WEAR CHECK POSITION 13	12/16/75
230			POSITION 14	
231			POSITION 15	
WEAR RUN			1 HR. $\theta \pm 5^\circ$ EVERY 5 MIN.	
232	25		WEAR CHECK POSITION 13	
233			POSITION 14	
234			POSITION 15	
WEAR RUN			3 HRS. $\theta = \pm 1^\circ$ SINUSOIDAL	
235	26		WEAR CHECK POSITION 13	
236			POSITION 14	
237			POSITION 15	
238	27		POSITION 13	
239	27	MANSFIELD	WEAR CHECK POSITION 14	12/16/75
240			POSITION 15	
241	28		POSITION 13	
242			POSITION 14	
243			POSITION 15	
WEAR RUN	26		4 HRS. $\theta = \pm 1^\circ$ SINUSOIDAL	
244	19		WEAR CHECK POSITION 13	
245			POSITION 14	
246			POSITION 15	
247	20		NO LOAD SINKAGE TEST	
WEAR RUN	19		1 HR. $\theta \pm 5^\circ$ EVERY 5 MIN	12/17/75
248	25		WEAR CHECK POSITION 13	
249			POSITION 14	
250			POSITION 15	
WEAR RUN	27		3 HRS. $\theta = \pm 1^\circ$ SINUSOIDAL	
251	26		WEAR CHECK POSITION 13	
252			POSITION 14	
253			POSITION 15	
WEAR RUN	20		3 HRS. $\theta = \pm 1^\circ$ SINUSOIDAL	
254			WEAR CHECK POSITION 13	
255			POSITION 14	
256			POSITION 15	
257	20		POSITION 13	12/18/75
258			POSITION 14	
259			POSITION 15	
WEAR RUN	19		1 HR. $\theta = \pm 5^\circ$ EVERY 5 MIN	

TACOM TIRE TEST SCHEDULE

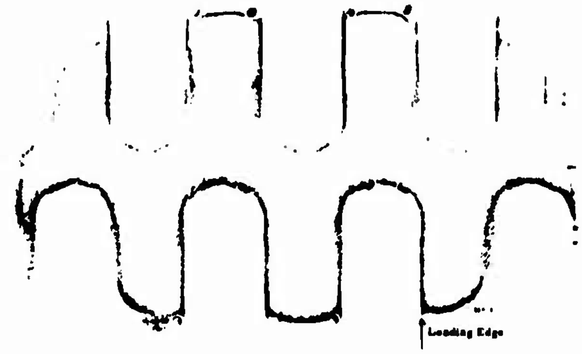
RUN NO. (20-1)	TIRE NO.	TIRE BRAND	TYPE OF RUN	DATE (1975)
WEAR RUN	20	MANSFIELD	1 HR. $\theta = 0$ BRAKING T = 100 FT. LB.	12/18/75
260	20		WEAR CHECK POSITION 13	
261			POSITION 14	
262			POSITION 15	
263	27		POSITION 13	
264			POSITION 14	
265			POSITION 15	
WEAR RUN	20		1 HR. $\theta = 0$, DRIVING T = +100 FT.LB.	
266	20		WEAR CHECK POSITION 13	
267			POSITION 14	
268			POSITION 15	
269	20		POSITION 13	12/19/75
270			POSITION 14	
271			POSITION 15	
WEAR RUN			3 HRS. $\theta = 0$, T = -100 FT. LB. BRAKING	
272	20		WEAR CHECK POSITION 13	
273			POSITION 14	
274			POSITION 15	
DIMENSION CHECK	21		MEASURE TIRE DIA. @ 1	
			@ 2	
			@ 3	
			@ 4	
			MEASURE TIRE WIDTH @ 1A	
			@ 2A	
			@ 1	
			@ 3	
MOUNT ON RIM	21	MANSFIELD	MEASURE TIRE DIA. @ 1	12/19/75
			@ 2	
			@ 3	
			@ 4	
			MEASURE TIRE WIDTH @ 1A	
			@ 2A	
			@ 1	
			@ 3	
WEAR RUN	20		3 HRS. $\theta = 0^\circ$ DRIVING T = +100 FT. LB.	
275	21		WEAR CHECK POSITION 13	
276			POSITION 14	
277			POSITION 15	
WEAR RUN			½ HR. $\theta = \pm 1^\circ$ SINUSOIDAL	
WEAR RUN			½ HR. $\theta = \pm 1^\circ$ SINUSOIDAL	12/20/75
278	20		WEAR CHECK POSITION 13	
279			POSITION 14	
280			POSITION 15	
281	25		POSITION 13	
282			POSITION 14	
283			POSITION 15	
284			POSITION 13	
285			POSITION 14	
286			POSITION 15	
287	28		POSITION 13	
288			POSITION 14	
289	20	MANSFIELD	WEAR CHECK POSITION 15	12/20/75
WEAR RUN (SINUSOIDAL)	22		1 HR. $\theta = \pm 1^\circ$ BRAKING T = 100 FT. LB.	
WEAR RUN (SINUSOIDAL)	23		1 HR. $\theta = \pm 1^\circ$ DRIVING +100 FT. LB.	
290	31		WEAR CHECK POSITION 13	
291			POSITION 14	
292			POSITION 15	
293	32		POSITION 13	12/20/75
294			POSITION 14	
295			POSITION 15	
WEAR RUN (SINUSOIDAL)			3 HRS. $\theta = \pm 1^\circ$ BRAKING T = -100 FT. LB.	
296	25		WEAR CHECK POSITION 13	
297			POSITION 14	
298			POSITION 15	
WEAR RUN (SINUSOIDAL)			3 HRS. $\theta = \pm 1^\circ$ DRIVING T = +100 FT. LB.	
299	22		WEAR CHECK POSITION 13	12/21/75
300			POSITION 14	
301			POSITION 15	
302	23		POSITION 13	
303			POSITION 14	
304			POSITION 15	

APPENDIX B. TIRE FOOTPRINTS



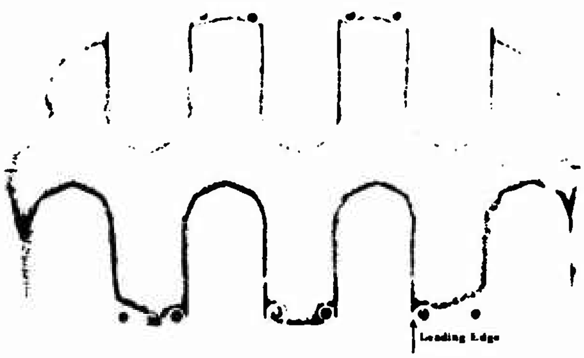
EAST ↓

Tire No.	28 (new)
Load	800 lb
Speed	-- mph
Pressure	24 psi
Slip angle	0 deg
Torque	0 ft lb
Run duration	0 min



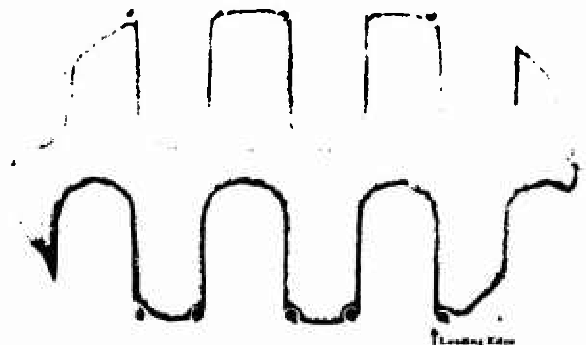
EAST ↓

Tire No.	24
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	$\pm$1 deg (square)
Torque	0 ft lb
Run duration	30 min



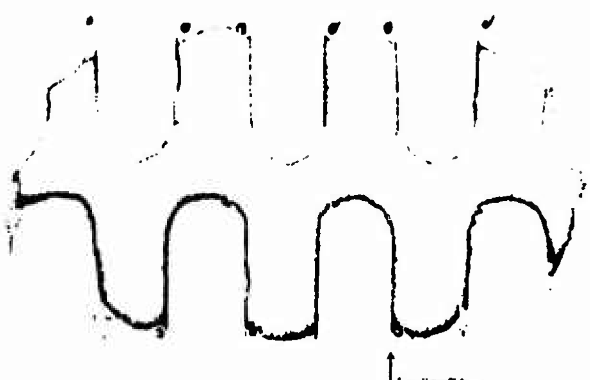
EAST ↓

Tire No.	19
Load	800 lb
Speed	30 mph
Pressure	20 psi
Slip angle	$\pm$.5 deg (square)
Torque	0 ft lb
Run duration	180 min



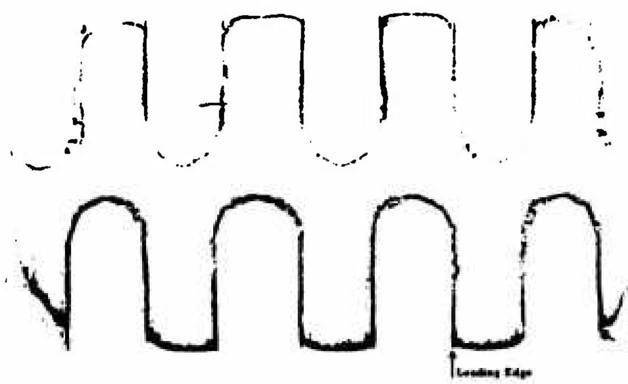
EAST ↓

Tire No.	25
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	$\pm$1 deg (sinus.)
Torque	0 ft lb
Run duration	180 min



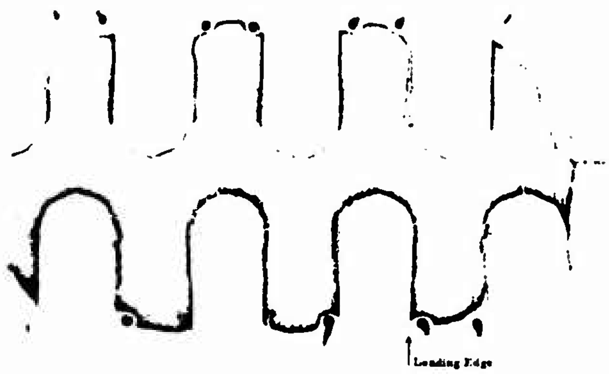
EAST ↓

Tire No.	23
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	0 deg
Torque	0 ft lb
Run duration	180 min



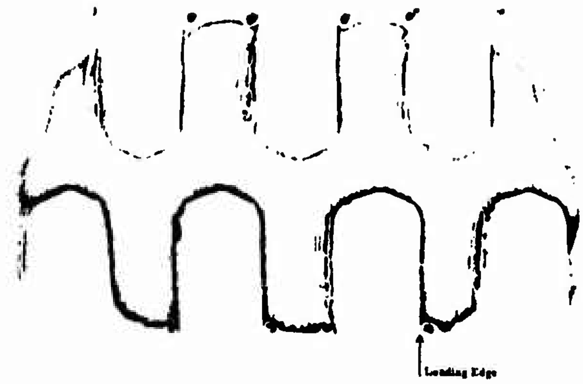
EAST ↓

Tire No.	26
Load	1000 lb
Speed	60 mph
Pressure	20 psi
Slip angle	$\pm$1 deg (sinus.)
Torque	0 ft lb
Run duration	180 min



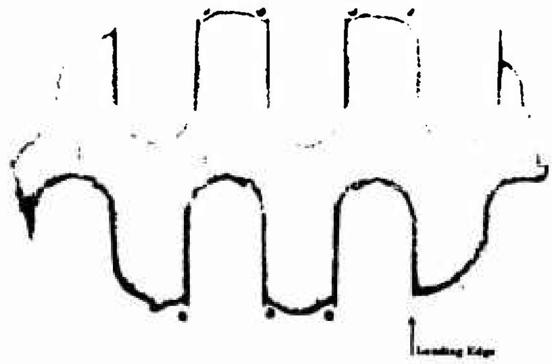
EAST ↓

Tire No.	27
Load	800 lb
Speed	60 mph
Pressure	16 psi
Slip angle	± 1 deg (sinus.)
Torque	0 ft lb
Run duration	180 min



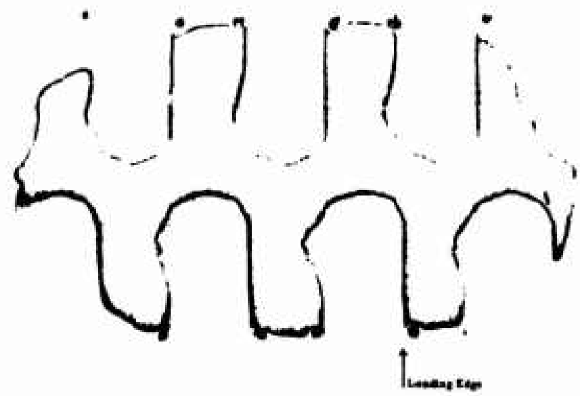
EAST ↓

Tire No.	30
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	0 deg
Torque	+100 ft lb (driving)
Run duration	180 min



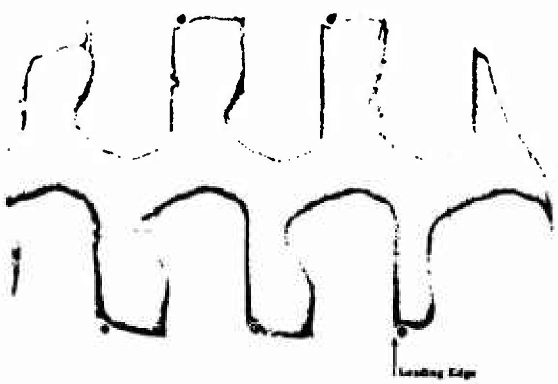
EAST

Tire No.	28
Load	800 lb
Speed	60 mph
Pressure	24 psi
Slip angle	± 1 deg (sinus.)
Torque	0 ft lb
Run duration	180 min



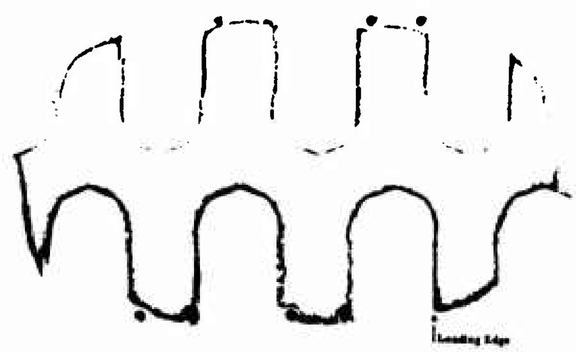
EAST ↓

Tire No.	32
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	± 1 deg (sinus.)
Torque	-100 ft lb (braking)
Run duration	180 min



EAST ↓

Tire No.	29
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	0 deg
Torque	-100 ft lb (braking)
Run duration	180 min



EAST ↓

Tire No.	33
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	± 1 deg (sinus.)
Torque	+100 ft lb (driving)
Run duration	180 min

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A SEMI-AUTOMATED PULSE-ECHO ULTRASONICS SYSTEM FOR INSPECTING TIRES

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The Transportation Systems Center in Cambridge, Mass. has developed and is presently evaluating a semi-automated pulse-echo ultrasonic tire testing machine. This paper describes the machine and explains its functioning in relation to the special requirements for ultrasonic inspection of tires.

A general overview of the tire-handling part of the machine is shown in Figure 1. As can be seen, it is an immersion system with a big tank about four-feet deep. This technique utilizes the effectiveness of total immersion to avoid any possibility of difficulties due to reflection of the ultrasound by air bubbles, which would be carried into the water as the tire rotates for scanning if it were only partially immersed.

As shown in Figure 2, the tire is mounted on a split rim and inflated with the aid of a pneumatic cylinder device which removes and installs the outer rim half. The rim halves are held together against the outward thrust of the inflation pressure by a heavy bayonet latch inside the tire. The cylinder thrusts toward the tire, grips the outer rim-half with a group of electromagnets (the outer rim-half is made of steel, nickel plated), and holds it while the tire-scan motor rotates the stub shaft 45° to unlock the bayonet latch. The air cylinder is then retracted to permit removal and replacement of the tire, and the process is reversed. The tire is inflated and deflated through the shaft assembly.

There are three such split-rim tire stations, on the ends of the three arms of a large spider or vertical carousel. Whenever one arm is at the load/unload position, the other two stations are totally submerged, one at a debubbling position, and the other at an inspection position. Once a tire has been mounted, it is moved to the debubbling station by a 120° rotation of the spider, driven by a 1-horsepower cam-actuated Ferguson index drive, shown in Figure 3. At the same time the previously debubbled tire is carried to the inspection station, and the previously inspected tire is brought to the unload/load station.

The Ferguson drive could index the spider in about two seconds if suitable baffles, curtains, etc., were added to control the splash. If tire mounting were totally mechanized, loading and unloading could also be accomplished in a few seconds. As we shall see, the actual ultrasonic scanning could readily be accomplished within about two seconds. If the data were evaluated automatically, a throughput of four to six tires per minute could readily be obtained. At the present stage of development, however, the index time is slowed down to about five seconds to avoid excessive splash. The tire mounting cycle is slowed to about 20 seconds for operator safety.

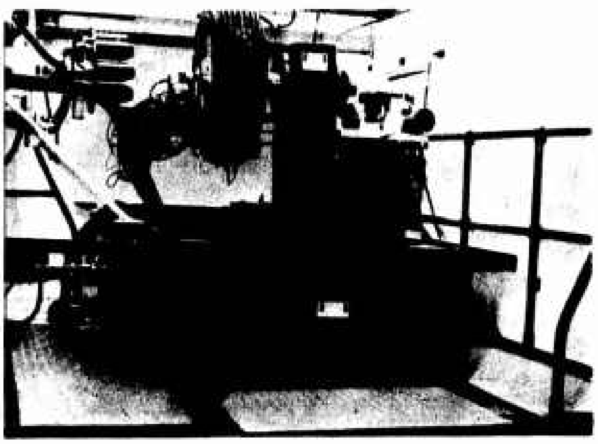

Figure 1. Overview of tire handler. A 3-station vertical carousel carries tires from the unload/load station shown, to a debubble station and an inspection station. The tire is totally submerged for debubbling and inspection to avoid entrainment of surface air bubbles.

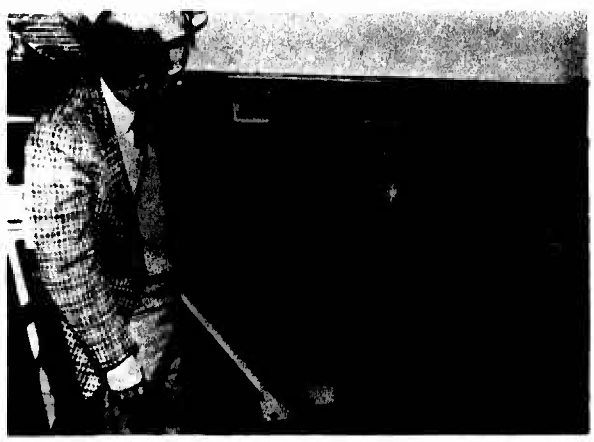

Figure 2. Tire Loading: Outer rim half is gripped by electromagnets and removed by a pneumatic cylinder. Outwaved thrust of inflation pressure is supported by an internal bayonet latch, which is rotated for engagement and disengagement by the tire-scan stepping motor.

While one tire is being scanned, the next tire is being debubbled by a set of high velocity water jets, but the load/unload operation cannot be conducted simultaneously, because reverse rotation is required to unlock the bayonet latch, and the three stub shafts are coupled mechanically by a roller chain drive inside the spider and driven by a single stepping motor. Finally, the scanning time itself is stretched out to 10 seconds because of the limited power of the scanning motor. For the present system, the mechanical limit on throughput is a little better than a tire per minute.

As shown in Figure 4, a set of transducers is arranged in a ring around the cross section of the tire. The transducers (up to 24 in number) are pulsed in sequence, and the returning echo signals are processed in sequence with the aid of electronic switching. Thus, the entire surface of the tire is scanned during a single revolution, which requires ten seconds. The transducers are sequenced at a rate of 2.4 kHz, so each of them is pulsed 1,000 times during the rotation, and 24,000 spots on the surface of the tire are interrogated during the ten seconds of the scan.

The system operates in the pulse-echo mode: each transducer sends out a short pulse of ultrasound lasting about two thirds of a microsecond, which travels through the water and into the body of the tire. Echo signals are reflected back to the same transducer from the various structural elements, e.g., belts, plies, etc., and finally from the inner surface of the tire. The only ultrasonic limitation on scanning rate is the requirement that all of the echoes from a given pulse be received before the next pulse is sent out, and for suitable transducer spacing from the tire, this time would be about 70 microseconds. In this case the same data would be acquired in approximately 1.7 seconds.

To make the pulse-echo technique work for tires, the second special requirement, no less important than total immersion, is to have the transducers perpendicular to the layered interfaces inside the body of the tire, so that specular reflections from the reinforcing elements can be received. To facilitate such mechanical alignment, the transducer support yoke is pivoted on sleeve bearings, at the main axis of the spider, so that it can be swung up near the surface of the water as shown in Figure 5. The spider is stopped halfway in an index operation and then jogged and hand cranked to bring the tire up to the surface, such that it will be in the same position relative to the transducers as in the inspection position. Thus, the coarse mechanical adjustments involving manual adjustment of clamping screws, slides, etc., can be reached while the transducers are totally under water, and it is possible to observe the echo signals on an oscilloscope. The criterion for proper alignment is simple: the echo signals are maximized and the layered structure is resolved to the maximum possible extent. Mechanical positioning of the transducers relative to the outer surface of the tire is not a practical approach to this problem because the outer surface of the tire is seldom parallel to the internal layered structure of the reinforcing materials.

To make the transducer adjustment procedure as easy as possible, each transducer is mounted on a small manipulator mechanism, so designed that the various required adjustments are as nearly independent as possible. Figure 6 shows one of these manipulators and illustrates the kinematics of the design. Transducer manipulators are mounted alternately on the top and bottom sides

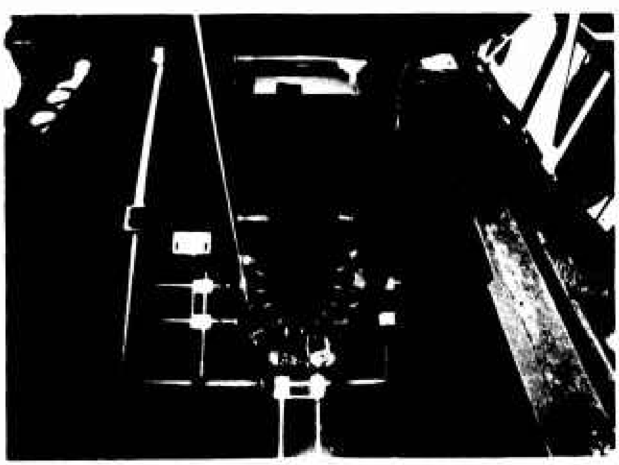

Figure 3. Indexing of spider - 120° rotation advances tires from load/unload station to debubble and inspection stations.

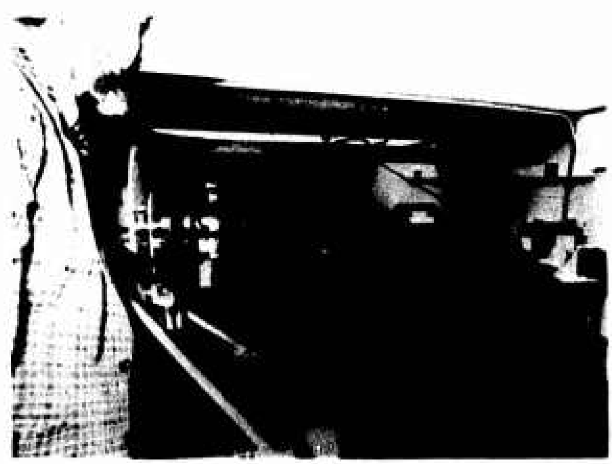

Figure 4. Transducers in working position.

of three arc segment rails having an H-shaped cross section, one of which is shown. These rails are called "ϕ-rails" because the position of each transducer along its supporting ϕ-rail corresponds to what we call the ϕ-coordinate, which measures angular position around the center of the cross section of the tire. The ϕ-angle is taken to be 0° towards the wheel axle, and increases from about 90° at the center of the blackwall (serial number) side of the tire, through 180° at tread center, to 270° at the whitewall side, etc. The three ϕ-rail segments can be positioned independently to make their arc centers coincide approximately with the local center of curvature for the adjacent ply layers in the tread region, and in each side of the tire, respectively. The normal to the tire structure then coincides approximately with a radius of the ϕ-rail, and would do so exactly if the tire shape were exactly circular over the corresponding ϕ-segment. To accommodate small departures from this ideal, a correction angle denoted by α can be introduced by moving the transducer on a smaller arc slide referred to hereafter as the "α-slide." Each α-slide can be positioned in or out along a radius of the ϕ-rail so that the arc center of each α-slide lies within the tire body at the depth of the ply layer of most interest. Motion along the α-slide is thus equivalent to rotation about the volume element of the tire being inspected, and changes in the angle of incidence in the beam can be made without changing the volume element being examined. Finally, the transducer can be moved in and out along a radius of the α-slide to achieve the desired water path distance, and each transducer can be tilted up or down from the cross section plane to make the beam axis perpendicular to the tangent plane in that direction too. This design may appear at first to be overly complex; however, a simpler design would be much more tedious to set up, because the various adjustments would be highly interacting. For successive tires of the same design the only adjustment which is very critical and likely to change much, is the α-angle. Remote adjustment of the α-angle is provided by a small stepping motor on each manipulator. This remote trimming capability permits precise reflection amplitude measurements to be made without the results being confused by minor changes in tire shape. Coarse adjustments that have to be made manually are only required when there is an appreciable change in tire size or shape.

Figure 7 shows an overview of the scan control and data evaluation console. To the right can be seen a rack containing 24 pulser-receiver amplifiers, one for each of the transducers. The main rack encircled by the operator's table contains the control electronics and the signal processing and display elements of the system. Lighted pushbuttons select and indicate scanning, signal processing, and display modes. Scan data displays are generated on a scan converter image memory tube and presented for evaluation on a large TV monitor. Signal processing is digitally controlled, and the scan-programmed signal processor provides up to 32 adjustable parameters which can have independent values for each of the 24 channels. A laboratory oscilloscope providing an "A-scope" presentation can be selectively triggered to monitor the effects of adjustments of the parameters for any one channel at a time. The knob panel directly in front of the operator, shown close up in Figure 8, is effectively switched to control 18 of the available parameters for the selected channel viewed on the A-scope. Digital values corresponding to the knob settings can then be loaded into the control memory. By

Figure 5. Transducers in position for coarse mechanical alignment.

Figure 6. Transducer manipulator kinematics.

repeating this process for each of the channels, appropriate parameters can be loaded to suit a given size and type of tire.

To assist the operator in the managing and recording of these parameters, a minicomputer provides a tabular display of the parameter values as shown in Figure 9 and permits entry or alteration of selected parameters via the keyboard, and/or re-entry of parameter sets from a digital storage medium.

Either the scan-data image-format displays from the large TV monitor, or the alphanumeric parameter displays shown on the small TV monitor, can be printed on paper by a video facsimile recorder (out of view in the figures). Finally, behind the operator's shoulders in Figure 7, you could see the reels of a video tape recorder. When a tire is scanned, the raw, unprocessed echo signals can be recorded. Thereafter, any of the various kinds of signal processing and display functions that the system is capable of can be accomplished from the tape-recorded signal, even after the tire is no longer available for tests.

Prior to describing the various signal processing and display functions of the system in more detail it is first appropriate to note some of the characteristics of pulse echo returns from tires which have motivated the design of this system.

Figure 10 shows echo signals correlated with the internal structure in the tread region of a belted tire where there were four body plies and two belt plies. The upper echo signal was obtained with a transducer having a nominal resonant frequency of 1.0 MHz, while the lower trace was obtained with a 5.0 MHz transducer. The upper trace shows a sharp, three half-cycle, return from the outer surface of the tire, which is characteristic of the echo signals seen from simple plane interfaces with highly damped transducers. Here we see the third special requirement to make pulse-echo inspection of tires work: highly damped transducers must be used so that the emitted pulse is short enough to give useful resolution of the layered structure. The return from the outer surface of the tire for the 5.0 MHz transducer appears more complex, merely because it is a summation of echoes from various surface elements of the tire at slightly different distances from the transducer. Reflections are seen from the deepest grooves in the tread pattern (e.g., at 5.0 cm on the 1 MHz trace and at 4.2 cm on the 5.0 MHz trace) because the ultrasonic beam cross section (about 1 inch in diameter) is occupied partly by ribs and partly by grooves. Shortly thereafter, a larger oscillatory signal is returned from the ply layers, and finally a pulse resembling the initial pulse in shape but inverted, and much broadened, is returned from the interface between rubber and air at the inner

Figure 7. Scan control and data evaluation console.

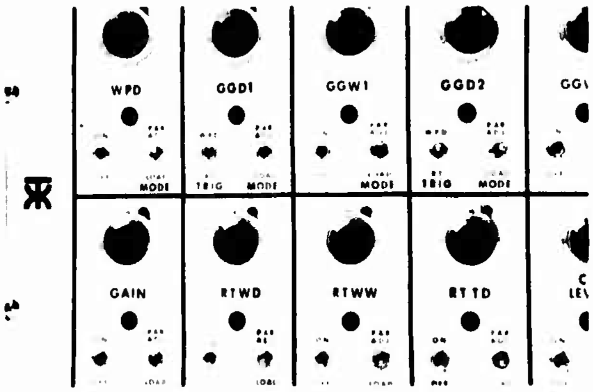

Figure 8. Parameter adjustment knobs. If mode switch is at parameter adjust, system uses knob-generated value for selected transducer instead of value from parameter memory. Load position puts knob value in memory.

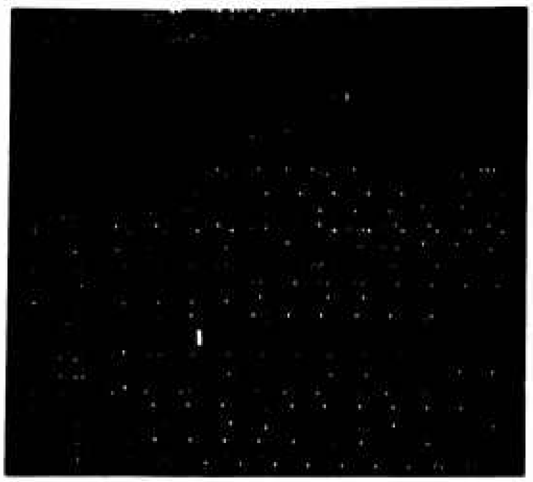

Figure 9. Tabular display of signal processor parameters. Numeric input will replace or increment parameter value for a particular transducer #, selected by positioning the cursor as shown, or for all transducers if cursor is positioned before beginning of a row.

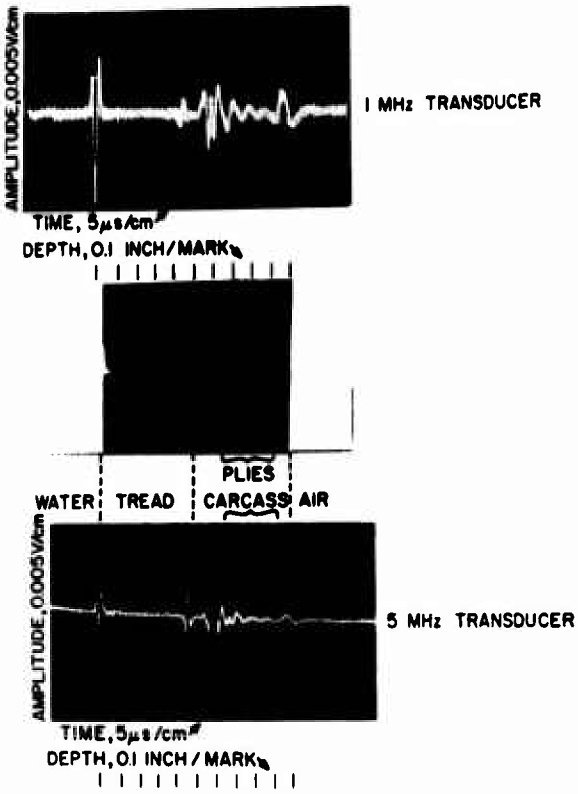

Figure 10. Reflection signal matched to tread structure of belted tire section.

surface of the tire. The amplitude of the return from the plies decreases very rapidly with depth, more rapidly for the higher frequency transducer, and returns from greater depths in the tire structure exhibit a low-frequency character. Since the incident pulse is short in time, it has a very broad frequency spectrum, and the returns from deep within the tire structure constitute primarily the low-frequency components of the signal which are less strongly absorbed and scattered. Because of these effects, it is not practical to use frequencies high enough to permit pulses short enough to cleanly resolve the successive layers in the ply structure. At this frequency the oscillatory return from the ply structure still exhibits interference effects between the returns from the several layers.

We have fitted our machine with 2.25 MHz transducers as a tentative choice for the trade-off of resolution versus penetration. Nevertheless, there is sufficient depth resolution to indicate the depth of a defect or anomaly relative to the various structural elements. There is certainly sufficient resolution to tell the difference between a bubble or air film on the surface of the tire and a separation or other defect with the body of the tire. The pulse-echo technique is thus inherently foolproof with respect to false alarm indications due to inadequate wetting or entrained air bubbles which may have caused difficulties with previous immersion ultrasonic systems which used through-transmission techniques.

Figure 10 simultaneously proves the promise and exhibits the fourth fundamental difficulty of inspection of tires with ultrasonics. Clearly ultrasound penetrates the tire structure, as is evidenced from the substantial return from the inner surface of the tire, even at 5 MHz, and echo signals are certainly returned from the layered structure of reinforcing materials. However, the echo signal is complex. Furthermore, it is not only unique to the particular tire construction (number of plies, materials used, etc.) the thickness of tread, etc., but the echo signal is different at every spot around the cross section of a given tire. The situation is entirely different from that usually prevailing in metals testing, where the body of the material is homogeneous, and the presumption is that any echo from an internal volume element represents a defect. In such a situation, a very simple form of automated processing is highly effective: a time window or range gate is established which excludes echoes from the front and back surfaces of the tested object, and echoes within this gate exceeding some established threshold correspond to defects. In tires the situation is not so simple. The internal volume of the tire body returns echo signals from the normally present cord structure. To be sure, echo signals from such gross defects as a separations exceed the background of reflections from normal tire structure and therefore, are detectable with gate-and-threshold techniques. However, at the time this machine was conceived, there was increasing evidence that separations were neither a necessary nor a sufficient cause for tire failure. Thus it appeared that more subtle anomalies needed to be investigated - anomalies which would not necessarily give echo signals rising above the background of normally present reflections from ply structures, but which might be evidenced by perturbations of the amplitude, or perhaps the phase, of the normally present signals.

The B-scan display technique provides a very sensitive means for detecting any such perturbations of the normally present echo patterns. Figure 11 illustrates the technique with scan data taken on a programmed-defect tire having separations approximately 1/2", 1", and 2" in diameter, deliberately introduced between the belt and the body plies. The reflection amplitude signal is used to intensity modulate the beam of an oscilloscope, which is then displaced vertically in synchronism with mechanical scanning produced by rotating the tire relative to the fixed transducer. The image display shown was produced in four sections by recording the face

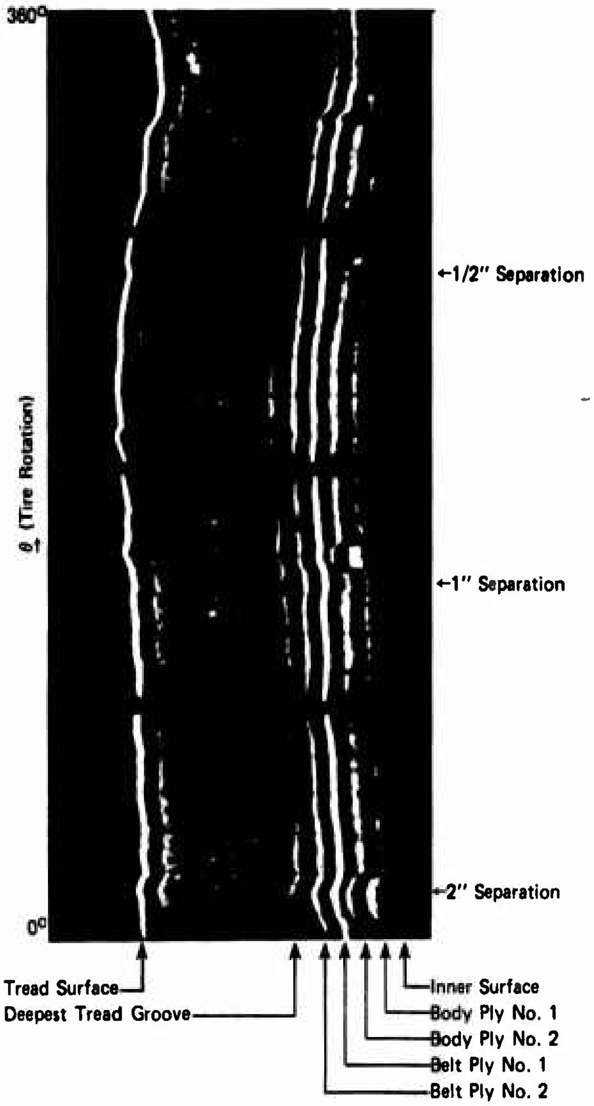

Figure 11. Single-channel B-scan display.

of the oscilloscope on Polaroid film during successive 90° intervals of rotation. The ultrasound is reflected from the tire, starting of course with the outer surface, and the further inside the tire structure the reflecting interface, the later the time at which the echoes return. Thus, the horizontal axis (corresponding to the time axis of the oscilloscope) measures depth into the tire structure. The bright line at the left of the display is the reflection from the outer surface of the tire, while the bright ridges on the right are the reflections from the belt and ply layers. The less intense line just to the left of the belt reflection comes from the deepest grooves in the tread pattern. Thus the depth of the tread is measured by the horizontal distance to this trace from the outer surface trace, and the nonuniformity of the undertread rubber is shown by the variable spacing of this line from the belt reflection. Large bright spots indicate strong echoes from the separations, clearly at a depth corresponding to the interface between belt and body plies.

The fact that the lines generated by reflections from the tire surface and ply structure are irregular, that is, that they are wavy rather than straight, indicates a lack of perfection in the roundness of the tire, since the position of a trace, of course, is a measure of the travel time (and hence distance) from the transducer to the reflecting structural element and back. Dimensional nonuniformity measurements can probably be related to force variation measurements. Furthermore, some kinds of shape anomalies appear to be worth checking as possibly safety related.

Pulse-echo ultrasonics provide a unique capability to make precise measurements of the dimensions and shape of the structural membrane of cord materials in an inflated tire. The position of a particular structural element can be measured directly from the ultrasonic echo time, rather than inferred by measuring mechanically to the outer surface and allowing for an assumed constant thickness of rubber outside this element. Since the velocity of sound in tire rubber is only about 10% higher than for water, the effect of variations in thickness of the outer rubber will be reduced by 90% as compared to a direct mechanical measurement.

We have seen that the B-scan display provides a powerful technique for revealing even very subtle variations in the echo returns from the tire structure. However, photographic recording would be prohibitively expensive for high volume use, and the time delay involved in processing would be incompatible with real-time evaluation. Both the materials expense and the processing delay are avoided by recording the display on an image memory scan converter tube. This device operates in some ways like a TV camera tube. It contains a semiconductor storage electrode on which an image can be written in the form of a varying density charge pattern by scanning it with an intensity modulated electron beam. The resulting charge image can then be read out by scanning the storage surface with the same electron beam, to give a video signal which will display the image on a TV monitor. Our system provides a number of signal processing and display formats, but the fundamental one is the multichannel B-scan display illustrated in Figure 12. Each of the vertical strips is a B-scan display for rotation of the tire from 0° to 360° for one of the transducers disposed around the cross section of the tire. As in the previous slide, the depth, or thickness dimension, of the tire structure is measured left-to-right within each B-scan strip.

The functioning of the signal processing and display electronics to produce this and other displays will be explained with reference to the functional block diagram shown in Figure 13. As the master clock produces timing pulses, the T-counter generates sequential transducer addresses to control the pulser-receiver multiplexer. A different transducer is pulsed every 400 microseconds, and the sequential echo signals are passed to the input of the signal processing electronics and also to the video tape recorder. The block diagram is shown with the first selection switch in the SCAN position, in which case a display is generated from the signals coming

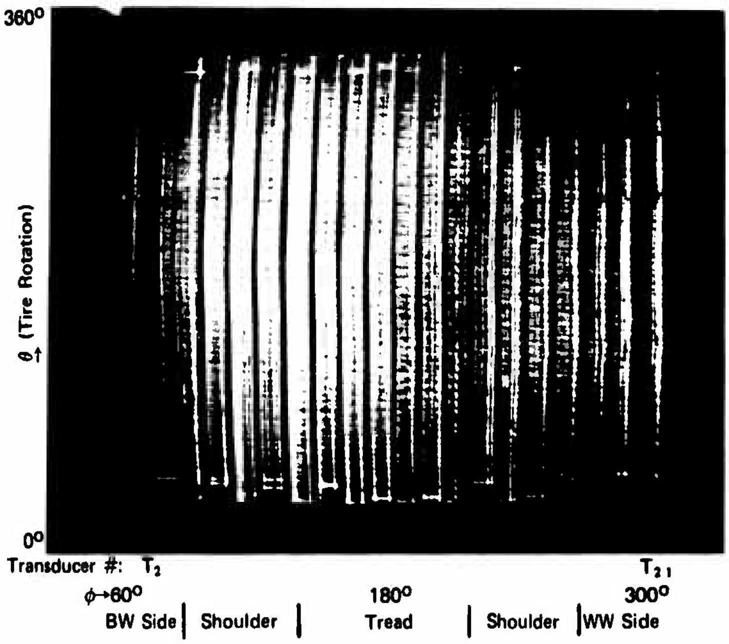

Figure 12. Multi-channel B-scan display. (-B signal, B-planar display mode)

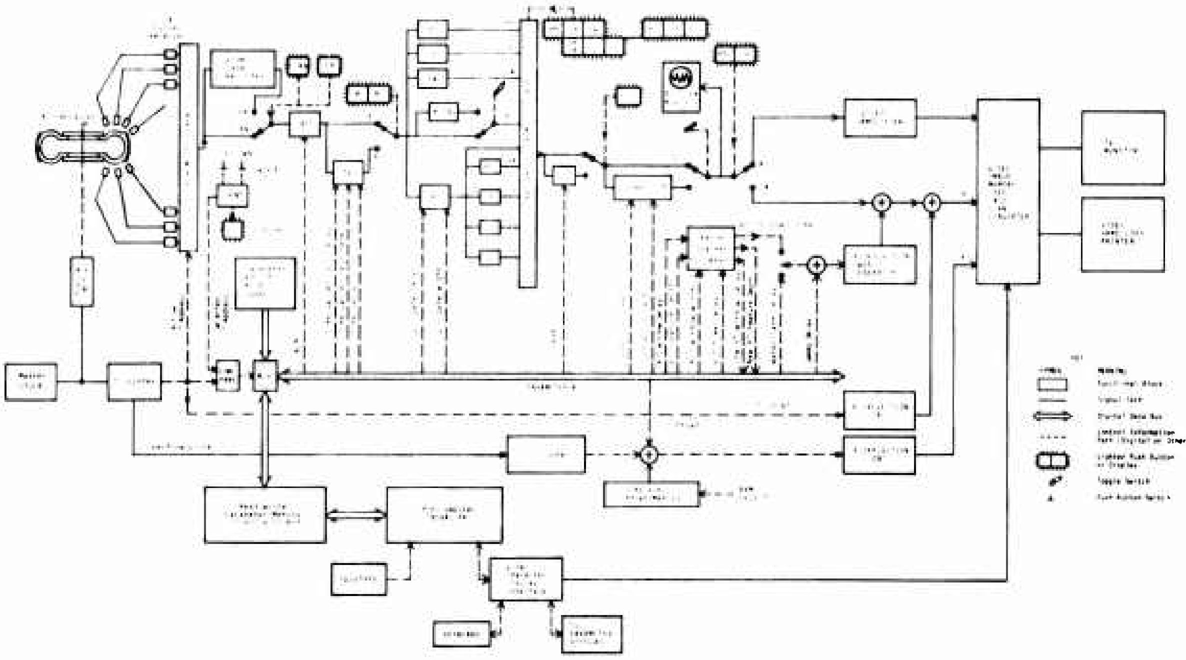

Figure 13. Functional block diagram indicating signal processing and display modes.

directly from the tire. In the PB or playback position, previously recorded sequential echo signals would be processed just as though they were coming live from a tire scan. The dotted lines indicate control of this switching by the lighted pushbuttons labelled SCAN and PB, which can be seen in the upper right hand corner of the mode control panel shown in Figure 14. Assuming the "B" option is selected by the next pair of interlocked buttons, the input to the signal processors will be affected by the scan-programmed gain values for each transducer, but not by the time-varied gain stage. If the B output of the signal processor multiplexer is selected by the next group of mutually exclusive pushbuttons, and the PBL display mode option is selected, (i.e., all switches in the positions shown on the diagram), the echo signal is passed directly through to the Z-input to intensity-modulate the electron beam of the scan-converter tube. The write beam is deflected to an appropriate x-position corresponding to the transducer number and a y-position corresponding to the rotational position of the tire by digital/analog conversion of the transducer count value and the θ-count value. At an appropriate time corresponding to the arrival of the echo return from the tire (normally the sum of Water Path Delay and Sweep Delay), the write beam is unblanked for about 32 microseconds, while the x-deflection sweep generator moves the beam across the width of one of the 24 display segments.

Figure 15 shows the A-scope presentation which guides the operator in adjusting parameters and selecting processing options for the previously shown display as well as certain others. The top trace shows the output of the pulser-receiver multiplexer with the oscilloscope triggered at the time of the "main bang" or excitation pulse for transducer number 7. At 20 microseconds per centimeter, only the echo signal from this transducer is seen. The operator will normally activate the Water Path Delay knob and adjust until the unblanking pulse covers the tire echo signal or as in this case, selects that part of it of most interest. The delayed sweep of the A-scope is triggered by the rising edge of the unblanking pulse, and the main sweep is intensified for the duration of the delayed sweep, which is made to coincide with the length of the unblanking pulse. The selected portion of the echo signal is shown with the expanded delayed sweep on trace 3. In this case the -B signal has been chosen to provide a maximum signal for separations, which have a negative reflection coefficient, since they represent a transition from the high acoustic impedence of tire material to the low acoustic impedence of air. A prominent separation reflection occurs at about 3.5 cm on this trace. This is the signal which was used to generate the multichannel B-scan display shown previously in Figure 12, and the separation, in the shoulder of the tire, accounts for the bright white spot at approximately θ=180° on the sixth B-scan strip of that figure (the 0th and 1st transducers were not mounted and the B-scan segments are not written).

Tires can easily be tested on a go-no go basis for defects such as this which give large signals compared to the background signals in their immediate neighborhood. The G-pushbutton is pressed, whereupon the button is lighted to indicate that the G-signal is the selected output of the signal processor multiplexer. The G-Gate Delay and G-Gate Width knobs are activated, and the gate is positioned to include the desired depth region in the tire. A rectification mode is then selected, in this case -P, since the negative peak is the most prominent feature of a separation. The -P signal rises in a positive direction proportionately to any negative peaks within the gate, and remains at the largest amplitude reached until it is reset for the next transducer signal. In the B-planar display mode, this signal intensity-modulates the display as before but the brightness level is constant once the largest peak is reached, and the result is

Figure 14. Mode control panel.

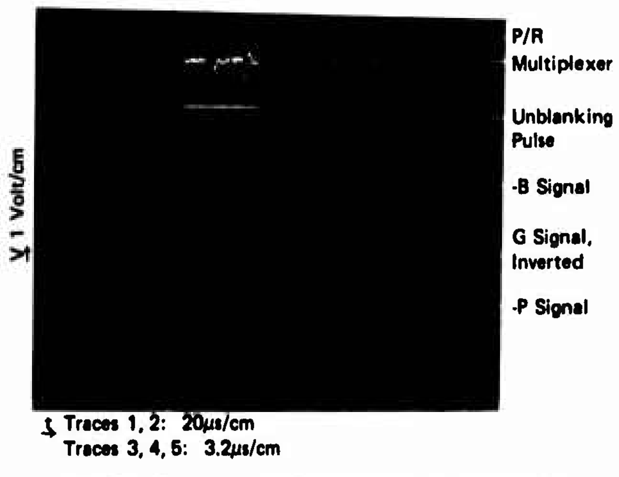

Figure 15. A-scope presentation showing processing options.

as shown in Figure 16. The format is the same as for the B-scan display: each trace starts at the background level and then goes to a constant brightness level measuring the peak amplitude. The depth into the tire at which the peak amplitude is reached depends on the gate setting. Traces with early gate settings appear bright over much of their width while those with late gate settings are bright only at the right hand edge corresponding to the lower depths in the tire. If the C_A pushbutton is pressed, the C-Analog display mode is selected, and the peak amplitude is used to deflection modulate a trace for each transducer as shown in Figure 17. The shoulder separation appears prominently on the sixth trace at a position corresponding to approximately $\theta=135°$ on the scale. (The shift in θ-position resulted from operator error; normally registration is maintained for successive scans on the same tire.)

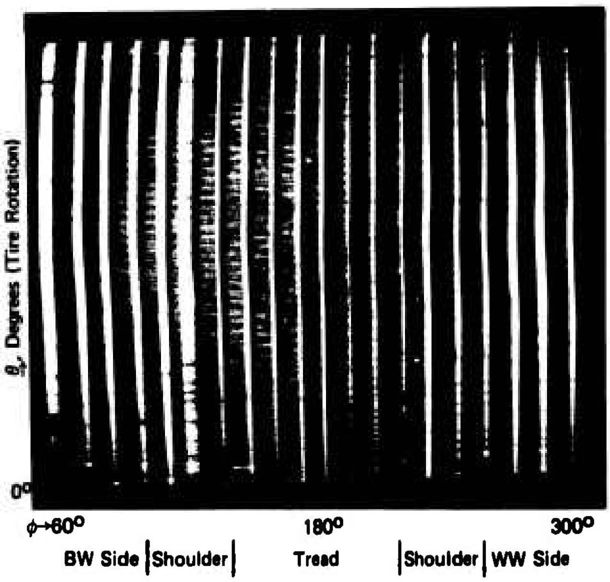

Figure 16. C-scan display - in B-planar display mode, gated and peak-rectified signal intensity modulates display.

In the parlance of ultrasonic testing, both of the last illustrated displays are "C-scans." A single quantity is derived for each pulse measuring some attribute of the signal within a time window or gate, and this result is plotted in a two dimensional display, both axes of which correspond to mechanical coordinate. In our case the two axes of the display correspond to surface coordinates on the tire. The vertical coordinate being the θ-direction generated by rotation of the tire, while the horizontal axis is the ϕ-direction corresponding to transducer position around the cross section.

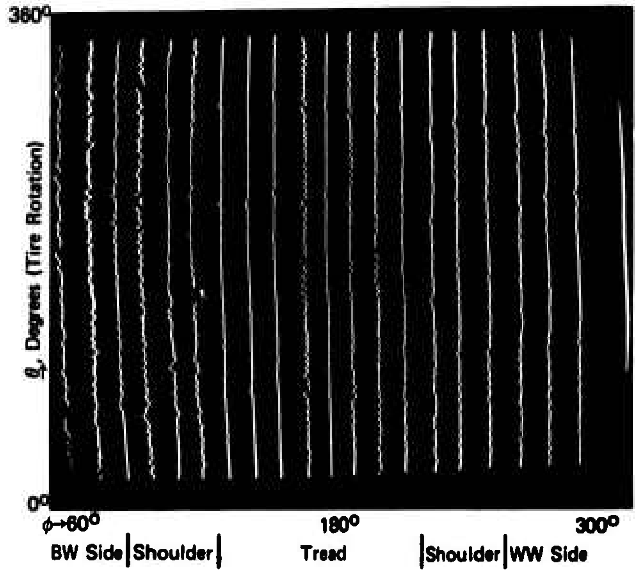

Figure 17. C-analoy display - Amplitudes of gated signals deflection-modulate traces.

The final step in go-no-go evaluation of the signals is provided by the C_L-module which compares the selected output of the signal processor multiplexer with scan-programmed threshold settings, which of course can be different for each transducer. If the measured attribute of the signal exceeds the threshold, a saturation level output is generated which will print a white spot using the B-planar display, with the result shown in Figure 18. The shoulder separation on channel 7 (printed sixth from the left) which we have been examining, is clearly evident. In addition, a smaller separation is evident at approximately $\theta=45°$. This separation is evident on the plane B-scan on careful examination. Incidently, the solid white bars which go all the way across each B-scan strip on all of the B-planar displays are electronic artifacts. They are not present on channels having 0 values for θ-offset. The bright white spot at about 1/3 depth into the tire on the display for transducer 16 at about $\theta=90°$ is an artifact of the scan converter tube.

As has been illustrated by a number of examples, any of the processing options indicated by possible switch selections and multiplexer output choices indicated on the functional block diagram

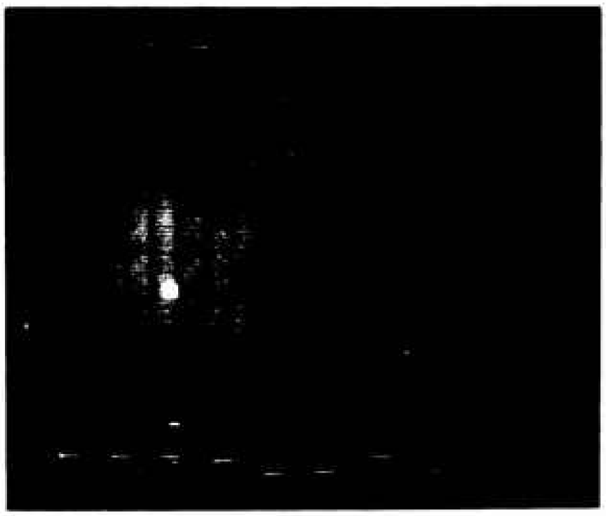

Figure 18. C-logic/B-planar display - Logic signal triggered whenever selected signal exceeds threshold intensity-modulates display.

can be used in combination with either of the display formats. The A-scope presentations for some more of the signal processing options are shown in Figures 19 and 22. The +H (positive half-wave rectified), the -H, and the FW (full wave rectified) outputs are intended primarily for enhanced B-scan displays. The B' signal is the original echo signal modified by programming the amplifier gain to increase exponentially, beginning at a certain onset time. The onset time (i.e., delay), the rate of increase, and a limiting value for the gain increase are all scan-programmable. As shown in Figure 20 this capability can be used to compensate for the attenuation which causes reflection amplitudes from the deeper ply layers to be smaller than for the outer layers. Besides enhancing a B-scan display, this provision is helpful in setting an automated detection threshold to be equally effective for defects at all depths. For this purpose the inner surface reflection, which is much larger than the levelled ply signals, would be excluded by the gate.

For automated detection of defects, one would generally want a measuring gate to cover that part of the reflection signal attributable to some particular structural element in the tire, for example, the outermost belt, the region between belts and body plies, the inner surface reflection, etc. While it is easy to set the gate delay and gate width so that any desired condition applies at a given spot on the tire, the amount of runout in tires is such that a setting made for one spot cannot be depended upon for the whole rotation of the tire. The usual answer to this problem in ultrasonic testing is what is called "first interface gating;" i.e., a timing signal is derived from the reflection from the first surface encountered in the tested object, and gate position is measured with respect to that signal. In the case of tires, this procedure appears undependable because in some cases there are serious variations in the thickness of some of the layers. Therefore, a range-tracking capability was specified in the design of this system. This permits a timing signal to be referenced to any prominent feature in the tire reflection signal, even to features which occur later than the timing signal itself. Actually, the time is referenced to the occurrence of the feature on the preceding pulse on the same transducer. This capability is implemented through a special digital processor which utilizes the resources of the digital control system. All of the signal processing time measurements are accomplished by counting cycles of a 20 MHz pulsed oscillator, which is started afresh with each main bang. A time to be measured, for example the Water Path Delay, is loaded as an initial setting for a counter which counts down at the 20 MHz rate. A timing pulse is generated when the counter reaches 0 and underflow occurs. The range-tracker processor establishes a trigger signal gate or window, adjustable in delay time (Range Tracker Window Delay) and width (RT Window Width). If the signal passes a threshold setting within this gate, a counter is stopped to measure the time of occurrence or "Feature Depth." The Feature Depth so determined is compared with the Feature Depth found on the preceding pulse, which was supplied from the parameter memory, and if the Feature Depth has changed, appropriate adjustments are made to the window position and to the range tracker trigger time by digital addition or subtraction, and the new values are stored back in the parameter memory until the same transducer is to be served again. Since the parameter memory at all times has stored the current values of the Feature Depth for each of the transducers, and since data paths from the parameter memory to the minicomputer are already established, we are very close here to a capability for digital acquisition of 24,000 dimensional measurements on the tire to any acoustically observable features within the tire structure.

But all of these considerations are related to efforts to apply automated defect recognition criteria of conventional gate-and-threshold techniques to defect detection in tires. Indeed, automated detection appears to be entirely practical for gross defects such as separations provided one optimizes the adjustments of time varied gain, gate positions, threshold heights, etc., to suit the particular type of tire being inspected. However, to detect possible anomalies which would perturb the normally present reflections, but which would not necessarily generate signals which rise above their average level, principal reliance must be placed at this time

on operator evaluation of the B-scan display. This procedure is immensely aided by the zoom capability of the scan converter tube memory. A small region or window on the surface of the image storage electrode is scanned and the resulting signal is displayed full size on the TV monitor. With such electronic magnification, the resolution of the TV monitor contributes no limitation and the full resolution of the scan converter memory is obtained. Magnified displays of two regions selected from the previously presented scan are shown in Figures 21 and 22. Figure 21 shows the region in the neighborhood of the shoulder separation. It is evident that the separation extends to the next adjacent trace as well. Figure 22 shows the display in the vicinity of the bright spot in the channel 16 segment attributed to an artifact on the scan converter tube surface. A perfect tire would be at least rotationally symmetrical, and the display would show a series of vertical lines which would be completely straight and uniform. These displays show many instances of irregularity and modulation. Unfortunately a certain amount of irregularity must be considered normal, and we are still learning to relate anomalies in the displays to irregularities in the tire. Furthermore, a great deal of work still remains to be done to relate observable anomalies to tire performance.

We have seen that a large number of parameters must be set to define any sort of go-no-go test criteria or even to produce an optimized display for operator interpretation. Furthermore, all of these parameters have to be adjusted to suit the particular type of tire being inspected. The minicomputer installed in the system helps the operator to manage all of the parameter data. The actual scan-programmed digital control is all implemented in special hardware and the system will operate without the computer. However, the computer accomplishes a very major reduction in the operator burden. The software is very elegantly designed to communicate with the operator through an alphanumeric video display and to guide the operator in the operation of the system. The "menu" of options shown in Figure 23 are displayed, and the operator makes his selection by keying in the appropriate option number and striking the "action" key on the keyboard. For example, option 1 transfers a parameter set from the hardware parameter memory to the computer memory. A basic purpose served here is that the computer memory is magnetic core, which is nonvolatile, that is, the stored data is retained even when the power is switched off, whereas the hardware memory is all electronic and hence is volatile. Option 6, "Modify Data Set From Keyboard," gives the tabular display we showed earlier in Figure 9. When the cursor on the display is placed to the left of a particular table entry the action key opens up space for a new line in the table and the operator can enter a new value or a plus or minus change. If the cursor is positioned all the way to the left at the label column, a keyboard entry will affect all 24 transducer channels in the same way, which provides a convenient way to make initial settings or global changes. A record of the settings used for any given test can easily be produced by copying the tabular display to the scan converter memory and thence to the hardcopy video printer. Options 3 and 4 provide for transferring parameter sets to and from paper tape. A modest addition of cassette tape or diskette peripherals would permit file-oriented storage of parameter sets, so that an operator would only have to key in an appropriate code to retrieve a data set prevoiusly arrived at for a particular type of tire. Besides loading the parameter set values, the computer can set standard or initial values for the α-angle alignment adjustments by outputting appropriate numbers of stepping motor counts for each channel. Coarse gain settings

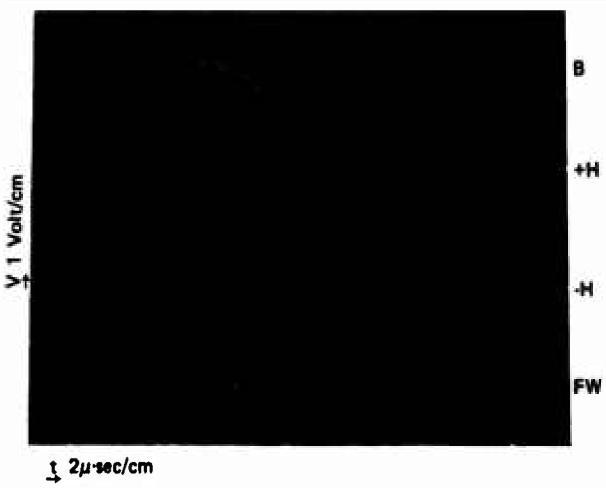

Figure 19. Processor outputs for B-scan displays.

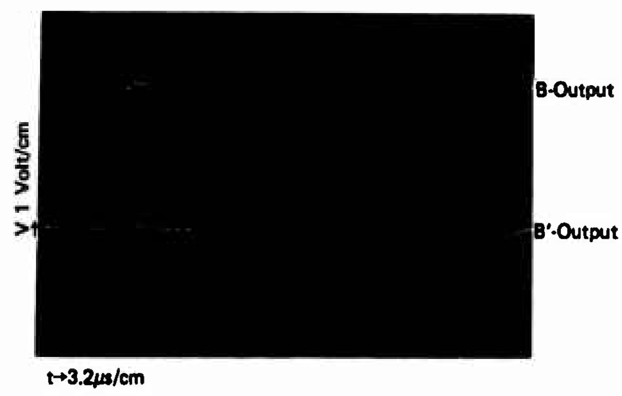

Figure 20. Time-varied gain.

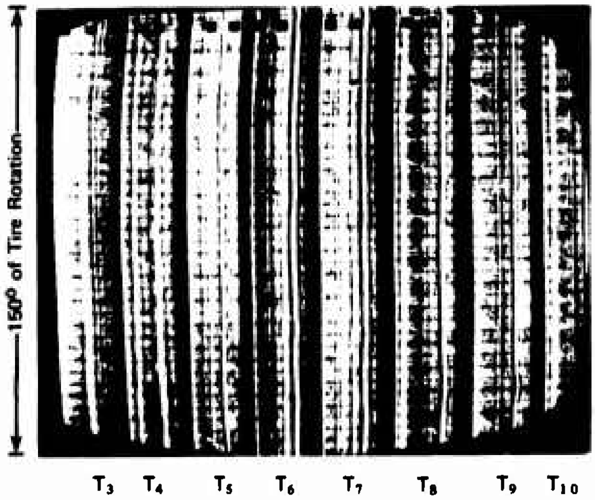

Figure 21. B-scan zoom display-#1 - Region of shoulder separation visible in Figure 12.

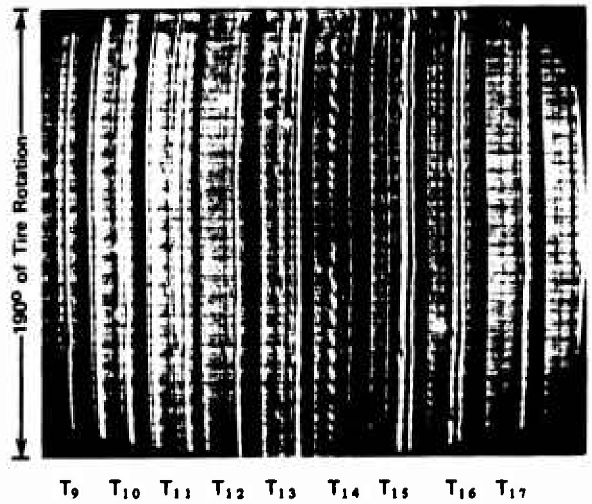

Figure 22. B-scan zoom display-#2 - Region in lower right of Figure 12. T_{13} shows an indication of a small separation between tread and body plies. T_{15} and T_{16} show perturbations of the inner surface traces suggesting possible separations, but probably caused by splices. The bright spot on T_{16} about 1/4 way from bottom is a display artifact.

made on the individual pulser-receivers cannot be set by the computer, but the settings made can be read by the computer and checked against the intended settings.

The general philosophy of the system design has been to recognize that while pulse-echo ultrasound provides a powerful capability for inspection of tires, it is inherently complicated by the complexity of internal structure and the unusual shape of tires. This basically geometrical complexity requires a rather complex setup to suit the individual tire before the full capabilities of the technique can be realized. In the system designed, the major burden of this complexity has been engineered into the system, and the operator has been relieved of as much of the routine bookkeeping as possible. Further, the use of digital control techniques permits the setup adjustments to be stored and re-used, so that the labor of arriving at them for various sizes and designs of tires need not be repeated. While this line of development has not been carried to the ultimate lengths that one might desire for production use, with a highly mixed population of tires, it has been carried far enough to be highly efficient for reasonably long runs of identical tires. For such runs, inspection times for the system as now implemented would be about two minutes per tire if the signals are merely acquired to video tape or processed to a single display for automated defect detection. Additional time would be added for real-time interpretation of the data displays, depending on the questions of interest and the degree of thoroughness desired. It is worth noting, however, that these inspection times are primarily limited by mechanical considerations. The ultrasonic limitation is to approximately two seconds for the data acquisition scan. With totally automated interpretation, which is possible now if the rejection criteria can be made specific, a throughput of six tires per minute does not seem unreasonable for a highly automated ultrasonic tire inspection system.

Note: The machine was designed and built under contract by Teknekron, Inc., of Berkeley, California, in accordance with specific system concepts and performance specifications developed in preliminary work at TSC. Mechanical systems were sub-contracted to RF Systems of Cohassett, Mass. The work has been sponsored by the National Highway Traffic Safety Administration under a program administered by Mr. Manuel J. Lourenco.

QUESTIONS AND ANSWERS

Q: RPN (Rubber and Plastics News) talks about the NHTSA using an ultrasonic unit to find tire flaws, and they talk about a $10,000 system for recappers, or a more sophisticated system available for $75,000 that will take up to five tires a minute. Are they talking about your piece of equipment?

A: I think I invented the one you're talking about. I tend to agree that it is a rather optimistic price. The price for hardware has gone up and up. It is gone up a good bit from the time the contract was let to the time it was finished. The total development cost that we have into the machine now is about $250,000. One comment I would make on that, though, is what I'd

Figure 23. Selection "menu" for programs to manipulate parameter set data.

like to call the till box analogy for ultrasonics. We built a machine here with the idea that we would look for "anomalies" in new tires which might be safety related. At the time we designed this machine, I say "designed" - of course it was designed under the government contract procurement procedure, and the spec was written which pretty much set the gross character of the thing. The detail work was done by Teknekron in Berkeley, California, and the hanger was built in the Boston area, and they flushed all the detail over there. The point is that we put all our power into this with the idea that we would hunt for whatever anomalies might be detectable by ultrasonics in the hope that we would find those that were relevant to safety, and if someone could have told us 3 to 4 years ago exactly what we needed to find and could have assured us if we found it that would solve all the problems, then life would have been much simpler. So for industry people who are interested in a particular problem, remember that ultrasonics is not a tool but a tool box and there may not be the right wrenches in the tool box of this particular system to fit your problem, like in the transducer areas, because the specialization of what you've got is really in that area. On the other hand, there's possibly a lot more in this than is needed so more specialized machines could probably be made cheaper or more expensive - a great area for trade-off depending on just what power you want. If you want resolution for small spots, you can use small transducers, but it's going to take you longer to scan, so this little problem lies somewhere between too much and too little. Hopefully something will be useful.

PRODUCTION TIRE INSPECTION WITH X-RAY

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Since 1972 the tire industry has dictated the need for high production X-ray systems. Development and design has required automatic handling of the tires as well as automatic optimization of X-ray manipulator and X-ray components. To date, this has led to the design of machines, presently installed, with cycle times, per tire, of between 9 and 20 seconds per tire. Now for the benefit of those of you who are not familiar with X-ray systems, cycle time is defined as that period of handling time from initial input of the tire into the X-ray system until the tire is exited onto the takeoff conveyor. It is not inclusive of the inspection time. Even with the installation of twelve of these sophisticated automatic systems, and this does not include the numerous manual X-ray systems, we cannot guarantee an inspection time per tire over and above the cycle time. Visual inspection of the tire is dependent upon many uncontrolled variables:

1. The competency of the X-ray inspector.

2. Magnitude of inspection parameters. Bead-to-bead, belt only, sidewall only, degree of measurement per parameter, etc.

3. Inspection for production control or the unexpected problem that requires analysis and verification.

4. Operator fatigue.

5. The obvious - tire size.

6. Detail and contrast sensitivity of the cord material involved. Rayon, polyester, nylon, and Kevlar will not provide the contrast of steel.

As the years progress, we will be in a better position to more accurately guarantee inspection times per tire, but at the present time we can only promise cycle time and not total time of inspection.

Again, for the benefit of those not familiar with the X-ray systems avai. ble for production, please see Figure 1 for the heart of the AID system.

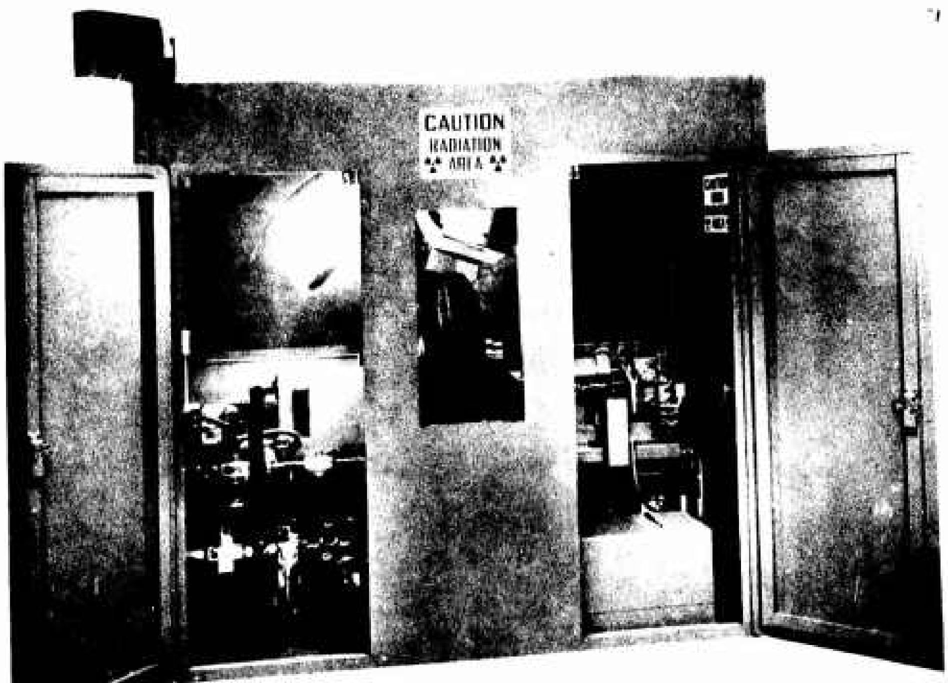

Figure 1

The AID air inflated device, Figures 2, 3, and 4 is a high production passenger/light truck system with a cycle time of 9 to 10 seconds per tire, inflated, with bead-to-bead capability, on all cord material. It uses fixed rims for mounting the tires. Tires are introduced into the overhead, horizontal acceptance chute, converted to the vertical acceptance input chute, released between the inflation rims, X-ray tube (Lighthouse-Picker patented) inserted, scanned from overhead, graded, and released to the lower roll-out take-away conveyor. The advantages to this system are the accuracies in mounting with air inflation resulting in precision measurements relative to tire component placement and symmetry simulating vehicle mounting. The disadvantage to this design is the lack of intermix capability. It must have a presorted input - in most cases, from the uniformity process.

Contrary to many established X-ray inspection techniques, an inflated tire can be inspected at a very high rotation rate - provided there is sufficient contrast as with steel and fiberglass constructions. With production inspection of tires, it appears that the majority of parameters of inspection are related to placement symmetry. To measure these changes it is necessary for the operator to be assisted with television monitor guidelines. High speed inspection is truly a process of comparison to the previous in three modes - sidewall no. 1, tread and shoulder, sidewall no. 2. The human eye can measure these changes very accurately, assisted electronically, in motion, with a continuum of one tire area.

The 10/27/750 high production intermixed X-ray system, Figure 5, has gained significant acceptance within the last two years. The total system consists of six major components.

a. Input and sizing station
b. Radiation enclosure
c. Tire manipulator
d. Imaging system with "C" scan manipulator
e. Operator enclosure
f. Operator console
g. Electrical control station

The advantages of this system are the ability to randomly intermix tire bead diameters from 10-inch to 27-inch tires with automatic handling and scan positioning - bead-to-bead with only on X-ray tube and imaging system plus image all tire cord materials. In order to simulate the advantages of air inflation, such as the AID unit, and maintain as near accurate centerline of tire rotation, for component measurement, a split manipulator design was incorporated using four spindles from the top and four beneath. Tire rotation is accomplished by the driven spindles with no dependence on tread area. Spindle

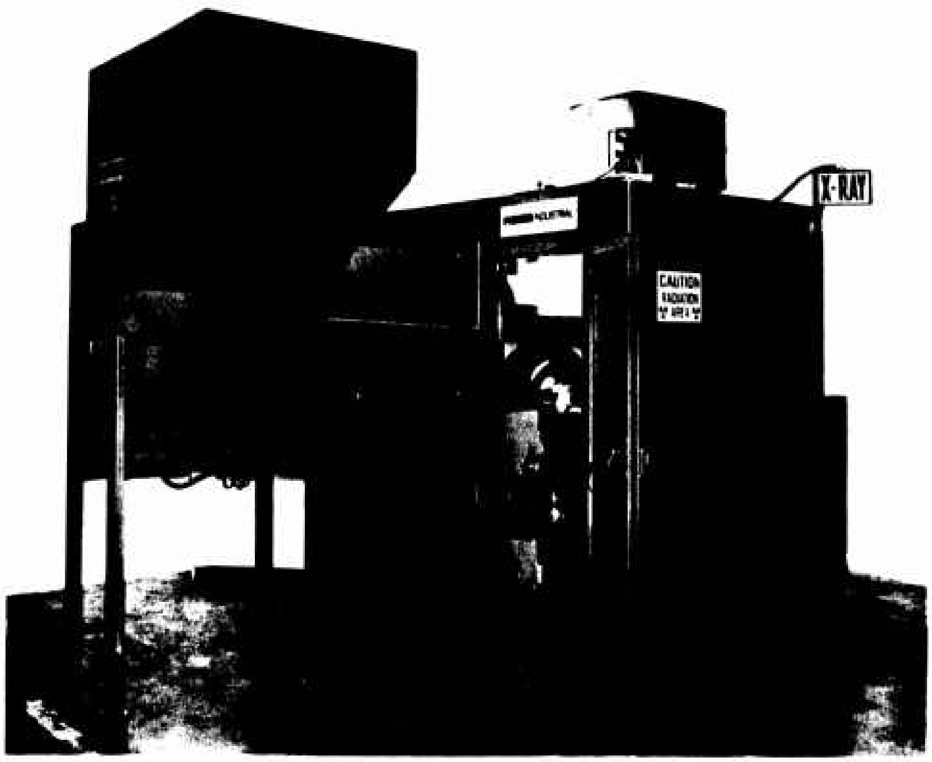

Figure 2

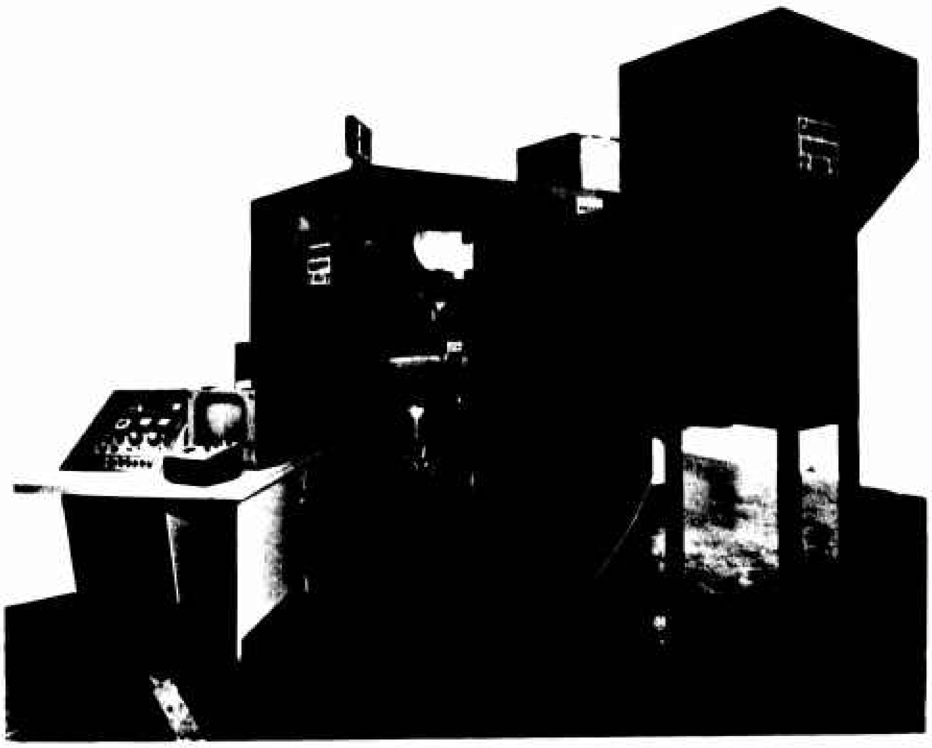

Figure 3

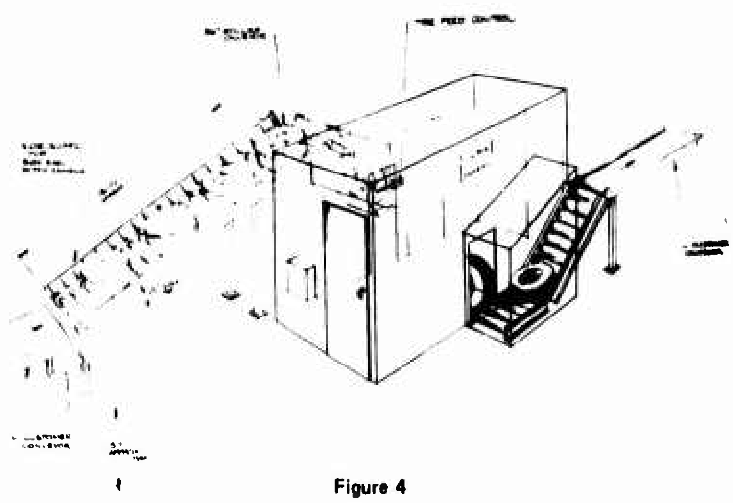

Figure 4

placement within the bead diameter is equidistant providing a uniform expansion to the rotation tire. Figures 6 to 12 show various close-up views of this system.

Why use a computer to control the intermix of tire sizes into the production X-ray system? Why not use a less expensive programmer? The advantages are many:

1. The computer will *simultaneously* adjust and optimize all system components to the intermixed tire system. It is *not* sequential resulting in reduced cycle times.

2. With the intermixed X-ray system, it is necessary for the tire manipulator, X-ray tube, and imaging system to optimize and position for maximum geometry performance. Over a wide range

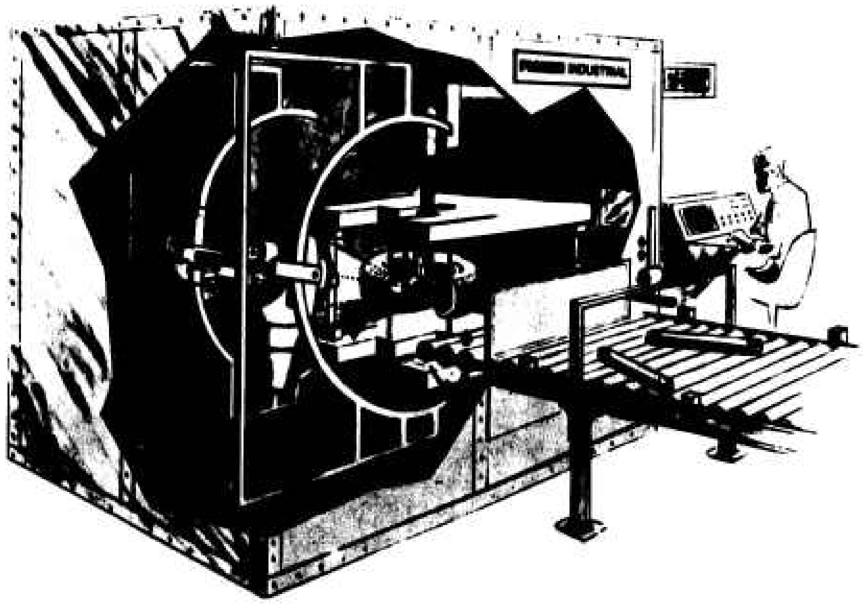

Figure 5

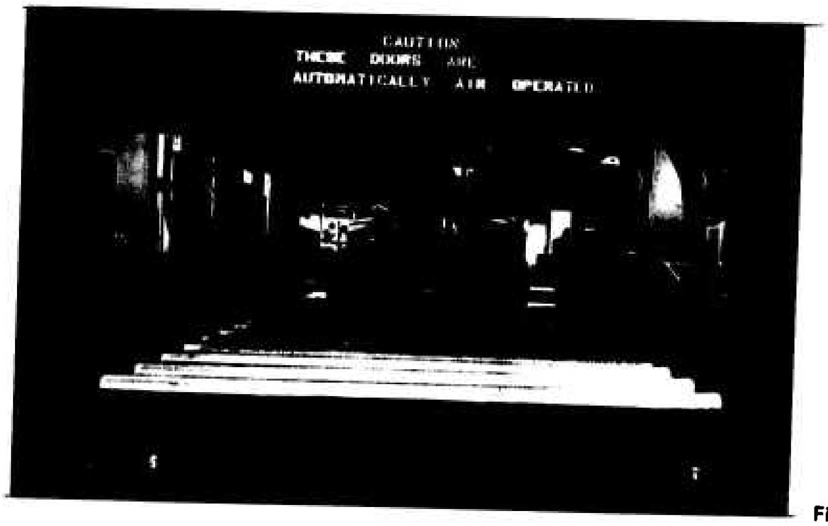

Figure 6

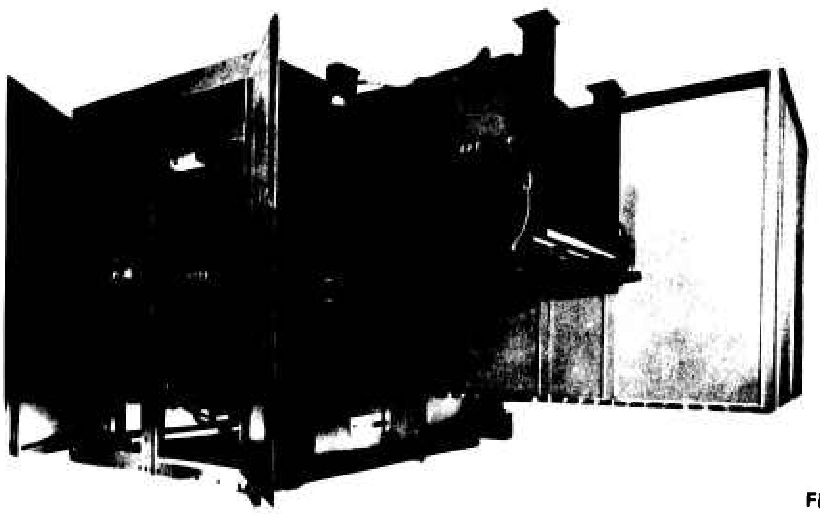

Figure 7

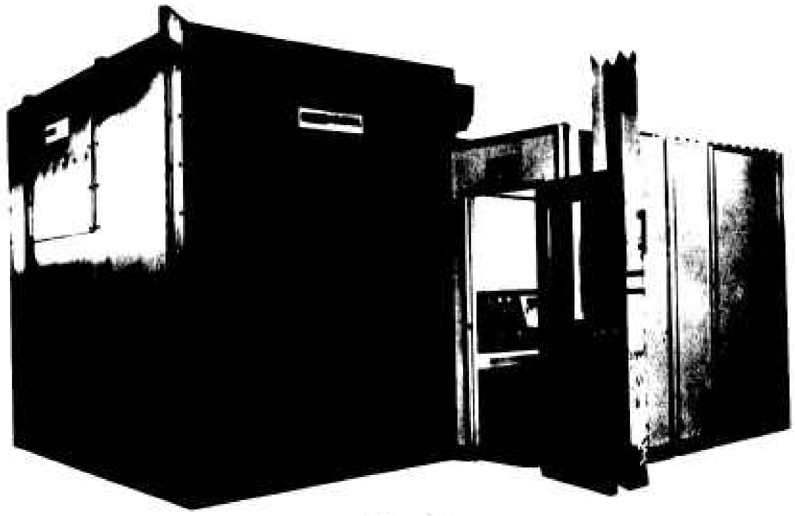

Figure 8

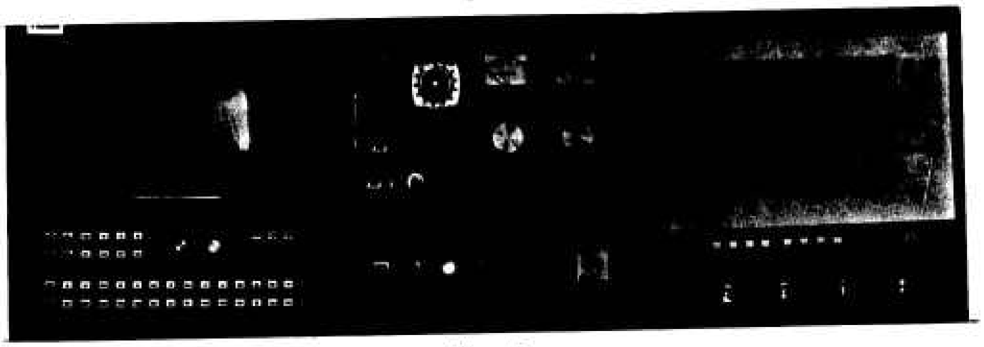

Figure 9

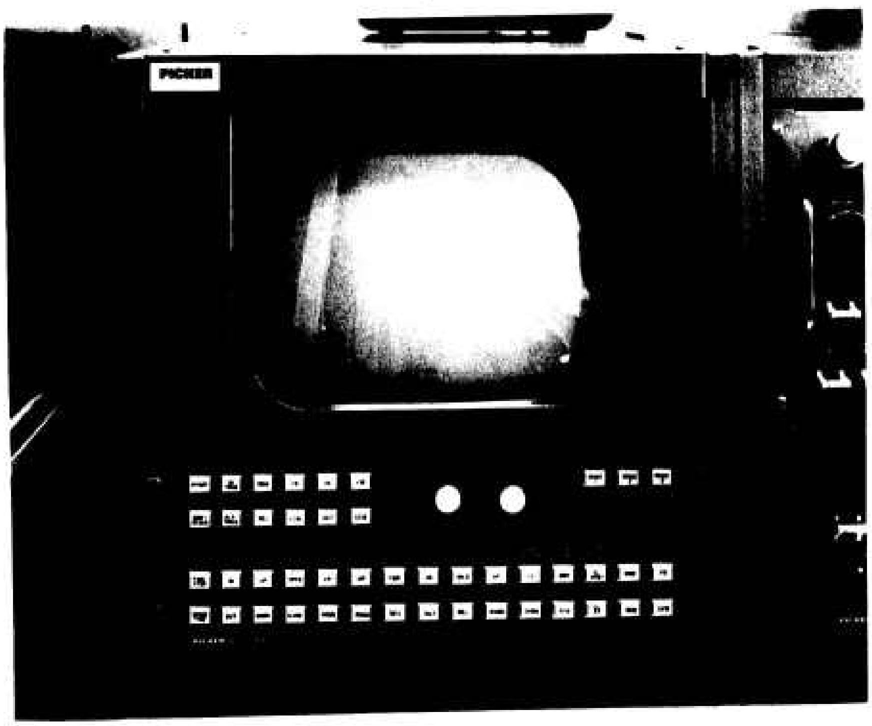

Figure 10

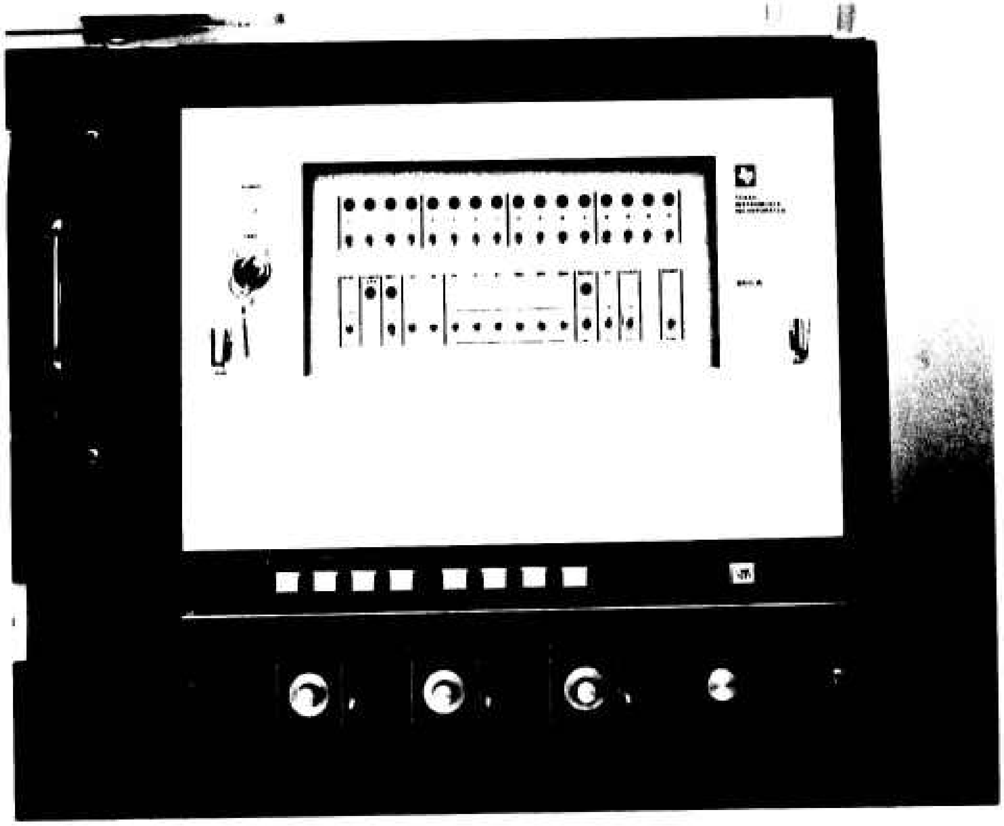

Figure 11

Figure 12

of tires - from a 10-inch bead diameter to a large 27 inch - this requires a change in position of *all* the system components. Only a computer can respond to this vast and simultaneous storage problem. The high production intermixed X-ray system can not view the 10-inch tire with the same imaging and X-ray tube placement as with the maximum 27-inch tire. There are no compromises as with fixed position.

3. Programmed imaging scans per intermixed inspections can be accomplished. With selected programs the computer will conduct the entire inspection automatically. The only responsibility of the operator is to grade the tire. After the computer is told what tire is on the input conveyor sizing station, the tire is conveyed into the manipulator, mounted by eight spindles on the stable bead areas, spread, and the X-ray tube is stroked into the tire torus at the exact tire centerline and insertion depth. The tire then rotates at a preselected speed with the imaging system advancing to the optimized distance relative to the X-ray tube, and programmed step scans are made bead-to-bead. In addition to the programmed viewing scans, the computer can superimpose parameter/television guidelines to individual tire sidewall or belt areas per tire size and type.

4. With the in-line production X-ray systems, "downtime" should be minimal. The 10/27/750 production system computer uses the computer to maximum advantage by providing a fault system. The operator, in the manual scan mode of operation, is warned of collision or improper limits by means of an automatic binary lighted readout panel. The system is shut down until corrected, and the lead-thru panel lights provide guidance to remedy the fault. The operator is also directed to one of 125 subsystems as to component failure.

5. The computer can track, record, and identify tire inspection daily by data storage and readout.

In conclusion, I would like to thank the tire industry for making these X-ray systems available today. Without their design requisites, cooperation, and perseverance, we would not have the capability we do today. Hopefully, next year we will be able to announce the availability of a high production X-ray system, using the same handling systems but with signature analysis. If the human body can be scanned automatically with X-ray, and it presently is being done with computer assistance, let's apply that technology to our endeavor!

A NEW DYNAMIC FORCE AND MOMENT MEASURING MACHINE PRESENTATION AT THE THIRD SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

John C. Ryder
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Massillon, Ohio

INTRODUCTION

For the past twenty years, researchers have been actively measuring the forces and moments generated by tires subjected to combinations of vertical load, slip angle, and camber angle.

Many design concepts have been attempted; and, today, there exist many machine configurations capable of generating such data.

These machines, however, were primarily designed to function in the laboratory environment and to generate data for research and development purposes. As tire force-moment properties and tire-vehicle interaction have evolved from research studies to well defined state-of-the-art parameters, the tire industry has new requirements for a machine system designed for production tire testing.

In 1974, Fabricated Machine Co. entered into a technical agreement with General Motors Proving Grounds relative the force-moment machine.

This formed the basis of the design of the continuous belt laboratory force-moment machine and the system we are discussing today, the FM 5000P Production Audit Force-Moment Measuring Machine.

The design criteria for the production audit machine include:

1. Continuous travel link belt roadway.
2. Capability to measure passenger and light truck tires.
3. Accuracies to 0.1% of full scale.
4. Capability of measuring lateral force and self-aligning torque.
5. Automatic control.
6. Computerized data reduction.

GENERAL

The FM 5000P Force and Moment System is composed of four integrated units; they are: flat belt-type road simulator, tire carriage and slip angle assembly, rigid main frame structure and integrated electronic unit. The flat belt is driven at a constant speed which is nominally two miles per hour. Dynamically controlled variables are normal (radial) force and slip angle. In addition to the controlled variables, lateral force and self-aligning torque are also measured and recorded. During each tire test, plots of lateral force versus normal force and aligning torque versus normal force are generated for all slip angles specified by the test. Calculated values for cornering coefficient, aligning torque coefficient, load transfer sensitivity, and load sensitivity are displayed on the CRT and printed.

Tire break-in and test procedure is conducted automatically in accordance with specifications entered by the operator prior to mounting each tire or group of tires.

The FM 5000P is designed specifically to provide high tire test throughput for production plant utilization. A cantilever spindle permits fast tire and wheel mounting and dismounting. A conversational program is incorporated to enable rapid break-in and test procedure set-up by the operator.

Complete machine calibration can be accomplished in a matter of two or three hours by means of proven calibration and linearization programs.

Accuracy, efficiency, and reliability compatable to the production environment are major features of the FM 5000P Force and Moment System.

Figures 1 and 2 show the general mechanical arrangement of the machine.

SPECIFICATIONS

Range

Normal Force	0 to 5,000 pounds
Lateral Force	0 to ± 4,000 pounds
Self-Aligning Torque	0 to 800 lb-ft
Slip Angle	0 to ± 6 degrees
Speed	2 MPH

Accuracy

Normal Force	5 pounds
Lateral Force	3 pounds
Self-Aligning Torque	1 lb-ft
Slip Angle	0.5 minute
Speed	0.1 MPH

Tire Size

Diameter	14" to 35" OD
Rolling Radius	6" to 17"
Section Width	15" maximum

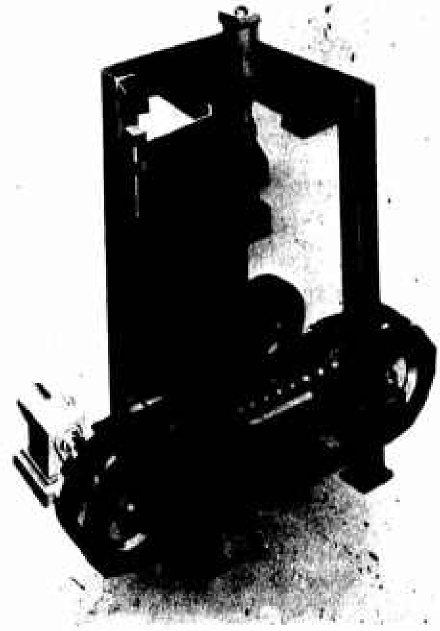

Figure 1

FLAT BELT ROAD SIMULATOR

A precision link belt is supported by two inflated 100 x 22.5 truck tires to form the road simulator. Normal force applied to the test specimen is transferred through the belt links to a supporting roller assembly. Truck tire axles and roller assembly are mounted on the main frame structure. Link pivots are made with aircraft needle bearings to insure long, troublefree operation. Belt tensioning and drive friction are adjusted by the truck tire inflation pressure. An in-line helical gear reducer connects one truck tire axle with a 50 HP AC motor. Gearing is designed to produce 2 MPH linear velocity on the belt when the drive motor is turning at 1,750 RPM. A tachometer generator provides a signal for continuous display and recording. Precision tolerances assure uniformity or roadway height within 0.0015 inch.

MECHANICAL CONFIGURATION

Refer to Figure 2 for details of the following mechanical configurations.

The carriage system is designed to input and read out test tire vertical load, slip angle, lateral force, and aligning torque with the accuracies specified above.

This framework system limits the test tire to the required number of degress of freedom to read out and input required parameters.

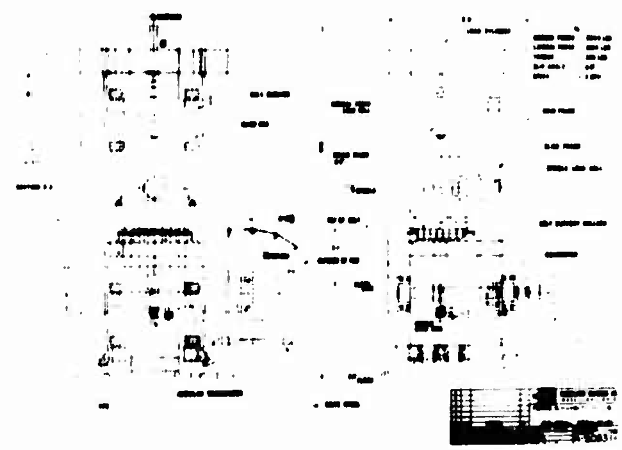

Figure 2

Vertical Load

Vertical load is input by an hydraulic cylinder controlled by a servo valve feedback loop.

A precision electronic load cell between the fixed frame and the vertical frame provides the direct reading of tire vertical load and feedback signal for the load control loop.

Thompson linear roundway bearings provide low friction linear travel of the vertical carriage. Precision alignment of the 60 case hardened ways provides negligible friction of the linear bearings and precision alignment typical of Fabricated Machine Co. test dynamometers proven throughout the world.

Slip Angle

A bell-crank mechanism inputs slip angle to programmed setpoints up to plus or minus six degrees actuated by a hydraulic cylinder and servo valve loop.

The slip angle is measured by a precision rotary DCDT providing infinite resolution of slip angle to the accuracy specified above.

A high-gain hydraulic servo loop assures the accuracy of slip angle and provides adequate force that setpoint slip angle is maintained throughout a test regardless of variations in vertical load or lateral force.

Precision hardened dowel holes between the rotating frame and the vertical frame provide calibration points at zero degrees and six degrees slip angle for calibration of slip angle.

Lateral Force

A special hub-mounted load cell affixed directly to the subject tire spindle provides direct readout of lateral force.

This system features a double flexture arrangement to resist deflections due to the subject tire's radial load but offers compliance in the lateral axis.

This load cell system was used originally on Fabricated Machine Co. laboratory dynamometers, and several units are in service around the world in similar applications.

Self-Aligning Torque

Direct reading of self-aligning torque is provided by a universal precision strain gage load cell mount . the front of the hydraulic cylinder that actuates the slip angle carriage.

A linearization table in the computer compensates for any nonlinearity imposed by the bell-crank mechanism at the higher slip angles.

INTEGRATED ELECTRONICS UNIT

The Integrated Electronics Unit is primarily a digital computer system capable of operation in both on-line and off-line modes. This group of integrated hardware executes software programs in response to operator commands. Data acquisitions, servo loop control, data reductions, data storage, data display, and hard copy generation are produced by this system. Numerous calibration, linearization, and diagnostic programs are provided for simplified maintenance and verification procedures.

Figures 3 and 4 show the system design and console physical arrangement.

System Interface

The System Interface is a specially designed communication device that permits the computer to receive information from and transmit control commands to analog devices. This interface accepts analog signals from force and displacement transducers, amplifies each, then multiplexes and converts signals to digital values under program control. It accepts digital values from the computer and converts them to analog values to be used as setpoint signals in normal force and slip angle control. Additionally contained in the interface are analog output signals for the X-Y plotters and numerous switch and indicator inputs and outputs in discrete bit form.

System Software

In addition to the assembler, compiler, drivers, and utility programs normally supplied by the computer manufacturer, Fabricated Machine Co. provides special operating system software specifically written to satisfy requirements of the machine.

The Operator Executive program is the primary resident of the core memory. This program incorporates real-time clock, automatic power failure protection, and operator interaction routines. The Executive configures, sequences, and monitors current operating programs, mathematic programs and tables commonly used by other programs are also maintained as resident in core memory.

On-line programs are those that perform during test machine operations. Among these are:

Dynamic Filter - Designed to provide numeric signal conditioning for force signals as a function of tire rotation velocity.

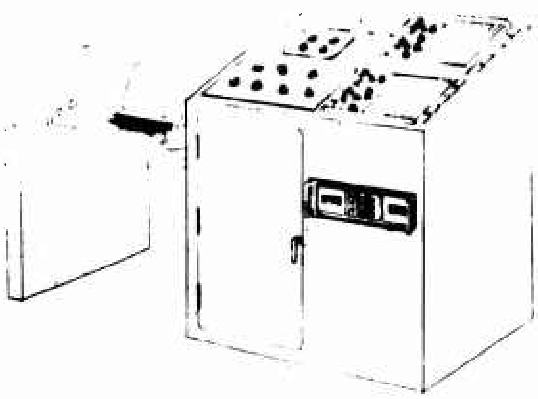

Figure 3

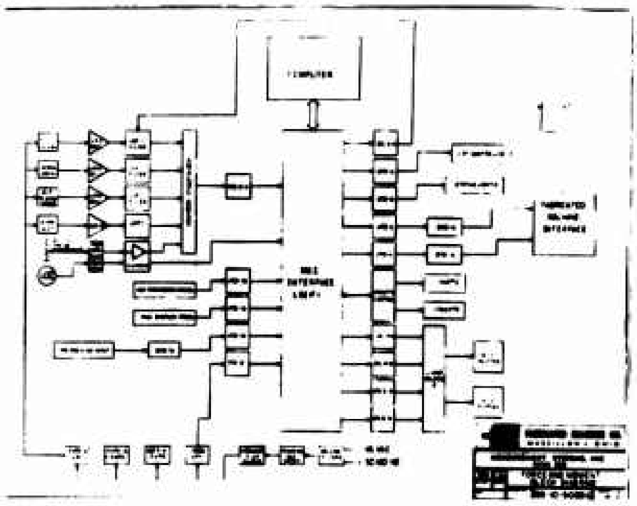

Figure 4

Linearization - A table look-up program designed to eliminate cross-talk from force cell readings.

Auto Zero - A program that compensates for any zero-drift or tire and wheel weight effects on force cells.

Loop Control - Provides supervisory servo loop control for normal force, slip angle, and road speed in response to measured and calculated values.

Data Display - Continuous updated display of measured test values.

Calibration - Forms look-up table during force-cell and transducer calibration with operator entered data from keyboard. Eliminates requirement for potentiometer adjustments.

Computer Functions

1. Radial force servo loop and acquisition
   Radial linearizer and calibration table

2. Slip angle servo loop and acquisition
   Angle calibration table

3. Lateral force acquisition
   Aligning linearizer and calibration table
   Radial to aligning cross-talk table
   Torque calculation

4. Self-aligning "force" acquisition
   Aligning linearizer and calibration table
   Radial to aligning cross-talk table
   Torque calculation

5. Raw data display

6. Radial calibration

7. Lateral calibration

8. Aligning calibration

9. Slip angle calibration

10. Calibration table print

11. Calibration table punch

12. Calibration table read

13. Tare values print

14. Heading data entry/print

15. Break-in specification

16. Test specification

17. Result

DATA RESULTS

Plotted Real Time

1. Lateral force versus normal force
2. Aligning torque versus normal force

Computed, Displayed, and Printed

1. Cornering coefficient at 1° slip
2. Aligning torque coefficient at 1° slip
3. Load transfer sensitivity at 4° slip
4. Load sensitivity at 1° slip
5. Accuracy of calculated curve fit versus raw data

X-Y Plots

The control console includes two X-Y plotters for real-time plotting of lateral force versus vertical load and self-sligning torque versus vertical load simultaneously.

This assures the operator of proper functioning of the mechanical and electrical portions of the machine exclusive of the computer manipulation.

Also, the operator at a later date can spot check the computed values by hand calculations based on these plots.

CRT Display

The control console includes real-time CRT display of vertical load in pounds, slip angle in hundredths of a degree, lateral force in pounds, and self-aligning torque in foot pounds.

This data gives the operator a backup of real-time functioning of the machine and also is used for calibration assistance.

Computed values are also displayed on the CRT as described below.

In setting up the machine, the operator calls up the schedule page from the keyboard and inputs the normalizing load and the warmup cycle prior to individual tires being run.

Then the operator has the freedom to leave the machine for automatic warmup and test cycle while he mounts the next tire in sequence for testing.

Computed Values

The computer makes a best spline bicubic fit of the raw data and stores for computation purposes the coefficients required for the above calculations and displays.

At the conclusion of the computation, the four characterizing functions are displayed on the CRT plus the accuracy of the fits including the maximum and the average difference of the computed fits versus the raw data.

Figure 5 shows a hard copy of the CRT display which is printed for each test tire.

CALIBRATION

Radial Load and Lateral Force

Radial load and lateral force are calibrated by loading a subject tire onto the Fabricated Machine air bearing-supported, standard, dual-axis calibration plate, which is supported by the flat bed itself. Figure 6 shows this device.

This unit includes precision electronic load cells oriented and instrumented to give direct digital readout of tire radial load and lateral force. The unit is delivered calibrated traceable to NBS standards in both axes, including internal precision self-calibration check.

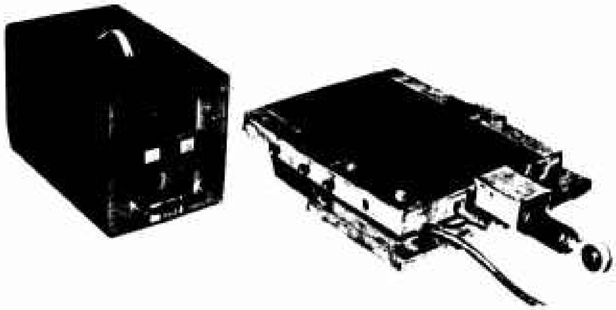

Figure 5

Both machine radial load cell and lateral hub-mounted load cell are, therefore, calibrated with this device as a standard.

Using the calibration mode and the CRT calibration table, several calibration points between zero and full span on both of these load cells are entered into the computer lookup table to compensate for nonlinearity and cross-talk in the load cells.

Slip Angle

As described above, precision dowel holes in the fixed frame and the rotating frame are aligned and bored at the factory on assembly of each machine to provide a fixed calibration point at zero degrees and ± 6° of slip angle.

Intermediate points are established by the computer based on a fixed lookup table which compensates for nonlinearities at the high slip angles due to geometry of the bell-crank mechanism.

Self-Aligning Torque

The self-aligning torque load cell of the FM 5000P is calibrated by a precision calibration load kit including electronic load cell and matched electronics which are delivered as a unit traceable to Bureau standards.

The machine framework is designed to accomodate fixturing of the calibration load cell between the actuating cylinder of the self-aligning torque load cell and the machine fixed framework.

DEFECT SIZE CRITICALITY STUDY IN NAVY AIRCRAFT TIRES

Douglas Baker
Naval Air Research Facility
San Diego, California

Presented by
Larry Klaasen
Naval Air Research Facility

INTRODUCTION

The purpose of the study was to determine the criticality of defects in Navy aircraft tires. The Navy is very interested in propagation of anomalies, because of the nature of the aircraft flown. For the most part, the aircraft have a single tire on each main landing gear, so if the tire fails, there is possibility of damage to the wheel and MLG system, FOD to wings and fuselage, and the possibility of losing the aircraft, and pilots. The Navy aircraft tires are exposed to a more hostile environment than aircraft in the other services or the commercial sector, in particular, the requirement for catapult launches and carrier landings, more aptly called a controlled crash. Also, there are multiple arrest cables, 1-3/8 inches diameter, which are crossed during landing and taxiing.

Therefore, this study becomes very important if it prevents the loss of one aircraft due to a faulty tire. The defects to be examined are separations or disbonds as determined by holographic nondestructive testing. It is an accepted general knowledge that separations in an aircraft tire will propagate. We wanted to know the criticality of these propagations: how fast will the separations grow, at what size will the separations be detrimental to the tire integrity, and if there are locations in the tire where separations are more critical.

EXPERIMENTAL

The tires used in this study are 26 x 6.6/16PR Type VII Navy aircraft tires. These are the main landing gear tires on the Navy's F-8. The tire is usually constructed with a reinforced tread, the exact design of course varies with each manufacturer. The tire studied has two tread reinforcing plies approximately half-way between the bottom of the grooves and the carcass plies. The tires were obtained through the regular supply system or were rejects from a Navy contracted rebuilder. All of the separations or defects were "natural," arising from the manufacture of the tires, and were not intentionally made.

The tires were inspected with an Industrial Holographics tire analyzer which was equipped with a krypton laser. The tires were hologramed and a map of the separations was made for each tire. As each tire was hologramed at a later date, the same map was used and the separations were recorded along with the earlier runs, so as to more easily see trend development.

After mapping the separations, the tires were sent to Wright-Patterson AFB (WPAFB) to be tested on the dynamometer. The test run on the dynamometer consisted only of a taxi-take-off cycle as used by the Navy in Military Standards 26533 and 3383. This test consists of a taxi for 10,000 feet at 23 mph and 12,000 pounds. The tire is stopped and run through a take-off consisting of from 0 to 200 mph in about 7,300 feet and loaded initially at 12,000 lb, and decreasing to 1,200 lb at lift-off. The requirements are for the tires to complete 50 cycles of Test A under these specifications.

The procedure was to initially plot the separations, the tires were then sent to WPAFB and a series of 5 taxi-take-off cycles were run. The tires were returned, re-hologramed, anomalies plotted, and returned to the dynamometer. This was continued for approximately 20 cycles with holograms every 5 cycles or until the tire failed. Those tires that have survived so far are now being run to failure.

RESULTS

I wish to show three examples of tires that have been tested and the propagation of anomalies within the tires.

1. The test report included a chart used for recording the separations. There are four 90° quadrants starting with the S/N at 0° and proceeding around the tire to 360° at the S/N again. The area plotted is from sidewall to sidewall.

The first tire, N10, showed some very large separations in the initial hologram (in H_0 on Figure 1). At this point the tire had not been run on the dynamometer. The separations varied from 1/2 to 3 inches long and most occur along the shoulder of the tire. The depth of the separation was not known. It could be at the reinforcing ply, undertread, or in the carcass.

After a series of 5 taxi-take-offs, the individual separations have merged into several large separations, almost one continuous separation (in H_2 on Figure 1).

During the next series of taxi-take-offs, the tire failed, completely throwing the tread, (H_2 of Figure 1).

The Military Specifications require 50 cycles for the tire to pass. This tire went less than 10 cycles. If it had been on a F-8, the least it would have caused is premature tire change, a loss of maintenance manhours, and placing the aircraft in a down status.

2. The next example, N8, showed only one separation initially. This separation was approximately 3/4 inch diameter and located near the center of the tread. See Figure 2 at 235 degrees. The depth of the separation was unknown.

After the first series of dynamometer runs, the initial separation had not grown, but the tire had developed three new separations of 3/8 inch diameter located in the center of the tread (in H_2 on Figure 2).

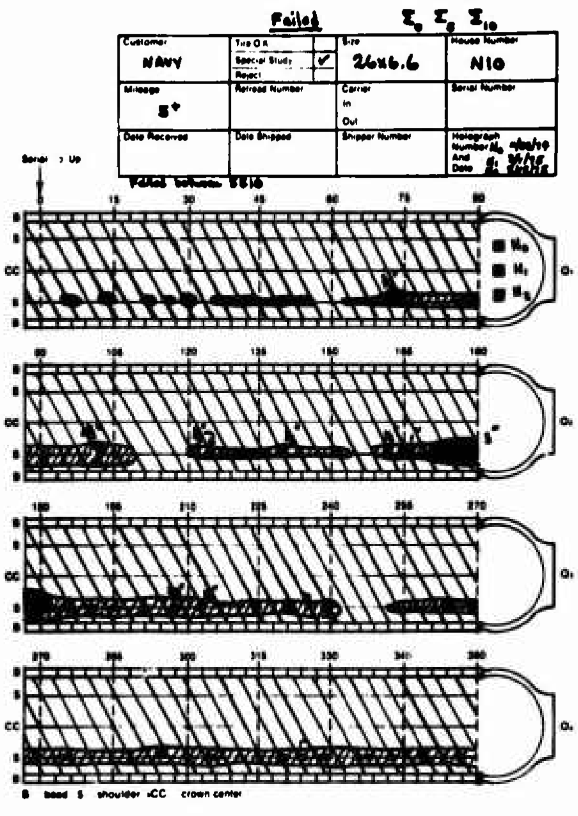

Figure 1

After 10 cycles, the initial separation had grown to 1 inch and the other separations had grown to 3/4 inch and 1 inch size (in H_2 on Figure 2).

The results were not available to plot the separations after the 15th and 20th cycles. After the 20th cycle the tire was run to failure, which occurred on the 28th taxi-take-off cycle.

3. For the last example, N4, the tire showed some very small separations in the tread area, overall a relatively clean tire (Figure 3).

After a series of 5 taxi-take-offs the separations had not grown but the tire had developed several small separations in the shoulder ranging from 1/8 inch diameter (in H_1 on Figure 3). It developed an area in the opposite shoulder that is characterized as weak but did not show any actual separations in it.

This tire then failed before the 15th cycle of taxi-take-offs, throwing the tread.

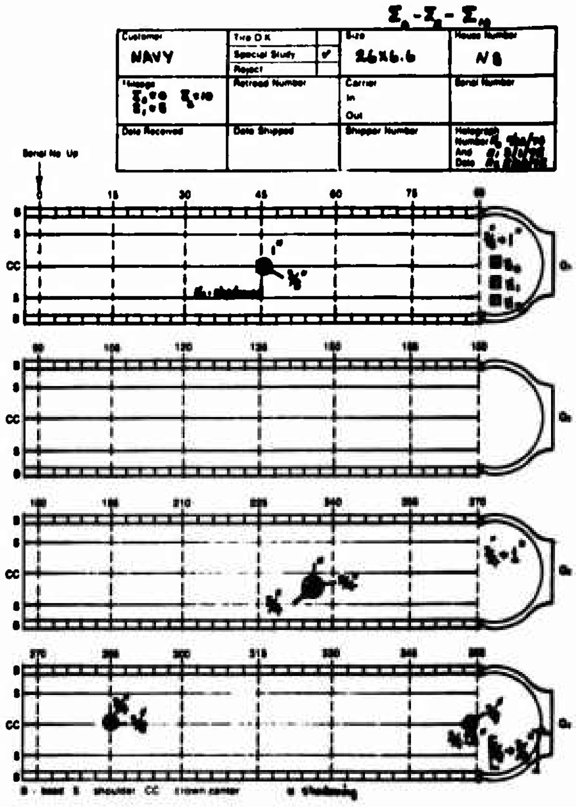

Figure 2

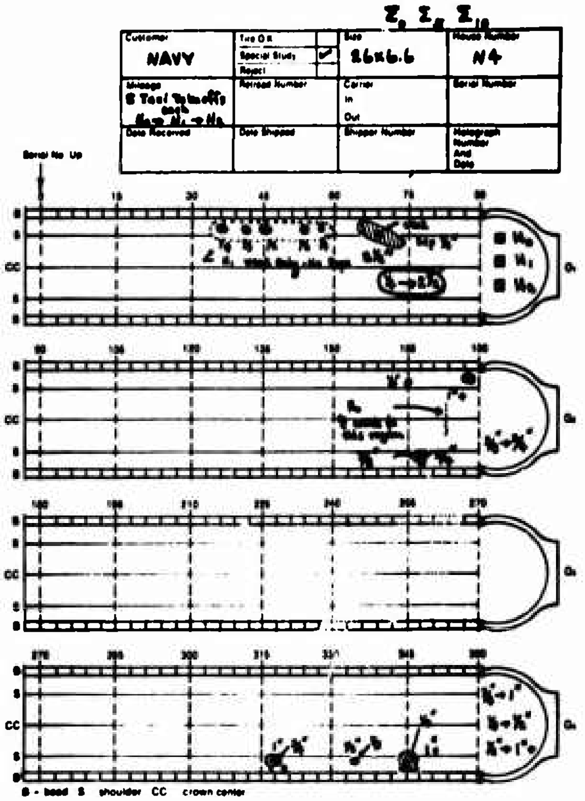

Figure 3

CONCLUSION AND SUMMARY

To summarize the results obtained thus far, there is a maximum size separation that the tire can handle.

We see 4-inch separations fail within the next series of 5 taxi-take-offs, 3-inch separations grew larger and then failed in 10 cycles; a 2-1/2-inch separation fail in the next 5 cycles, and a 1-1/2-inch separation grew to 4 inches and fail within 10 cycles. The failures resulted in a complete loss of the tread.

Thus, we see that the size of approximately 3 inches will cause a failure in very short time on the dynamometer.

We have seen what happens to the tires containing large separations. The following description is of some of the smaller separations.

We saw the separations grow during a 5 cycle series from 1/8 inch to 1/2 inch, 1/2 inch to 1 inch, 3/8 inch to 3/4 inch, 1 inch to 2 inches. In one case the separation grew at a slower rate, a 1-inch separation grew to 1-1/4 inches then to 1-3/4 inches after 10 cycles.

We observed that the small separations enlarge at a fairly rapid rate on the dynamometer. Thus far, any tire with a separation in it, could be expected to fail.

As I have mentioned, this study is approaching its conclusion. The results presented were an initial view of some of the early work. The tires are now being run to failure on the dynamometer, and final analysis of the tires will be performed to determine the cause of the failures and the depth of the separations.

I wish to thank Dr. Grant, Industrial Holographics, for the NDI work; CAPT. Larry Wilder, Wright-Patterson AFB, for the dynamometer testing; and Gwynn McConnell, Naval Air Development Center, for their contribution in this study.

QUESTIONS AND ANSWERS

Q: Where were your dynamometer failures related to these holographic separations?
A: I didn't quite understand the question.
Q: Were you able to trace the failures back? Were they directly related?
A: We haven't had a chance yet to examine all of the tires with the exact location. I have made a preliminary inspection of some of the failures and they appear to be related to some of the major separations, but the exact locations I don't know yet.
Q: Do you know that these were separations in the first place and not just the tire based on your experience of reading holograms?
A: Yes. Separations were determined from previous experience to be there and the sizes of them were verified by cutting up the tires and actually looking at the separations.
Q: What is the time between cycles on the dynamometer when you are stopped for a cool-down?
A: I don't know.
Q: Can you tell me about the defects that you have have uncovered; did they all grow or did any defects not grow?
A: The defects that we're looking at have all shown growth on the dynamometer. The tires presently are being inspected after rebuilding, and we don't have the inspecting pressure on used tires that we have on the new tires.
Q: Is it possible that a location of a separation can vary in importance?
A: That is a possibility. Another reason for the study was the criticality as to location of the defect. Now this particular tire has reinforcing plies. A lot of defects occurred at what appeared to be the shoulder area or at the edge of the reinforcing plot. On the dynamometer, it is felt that it would stress more at the edge of the reinforcing part. It may have different growth factors depending upon where the separation is.

THE STRUCTURAL INTEGRITY AND UNIFORMITY OF AIRCRAFT TIRES AS OBSERVED BY HOLOGRAPHY

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This discussion is predominately on the subject of structural integrity and structural uniformity of aircraft tires with some comparisons made on truck tires.

Much of the work we have been doing on aircraft tires is extremely preliminary. We have tested only a few thousand to date. Normally our testing facility tests about 20 to 40 tons per month. We have learned rather painfully from mistakes which we have made testing truck tires in past years, that it takes a very large data base over an extended period of time before one can establish with any degree of credibility exactly what is taking place in terms of specific failure mechanisms. Our basic objective is an understanding of the life expectancy or durability of a tire. How does one get his money's worth out of a tire? How, basically, does it fail, and when is it going to fail? In the case of truck tires, we look at the diameter of a given separation in a tire as a function of the mileage. We follow a given tire up to 160,000 miles. For example, a quarter inch wide separation in a new radial truck tire will grow linearly as a function of mileage up to typically one or more inches within 100,000 miles. We plot the separation diameter as a function of mileage through repeated tests at various mileage points. We then observe the size of the separation just prior to the failure point. We note, within the limits of statistical error, that in general there is a linear relationship between separation size and mileage, which almost always results in separation propagation which is quite predictable in other tires of identical construction under similar road and load conditions.

Now, let us return to our discussion of aircraft tires. If you want a good dose of humility in terms of studying failure mechanisms in tires, just move from truck tire studies to aircraft tire studies. Aircraft studies are much more difficult. The initial sample of a given size of new R-0 tires typicall have few separations in them, 1% or 2% on the average, 3% or 4% at the most. However, after watching them beyond R-1, the first recap level, or R-2, the second recap, we will sometimes see separations suddenly appear along with a progression of poor structural uniformity in the tire. Separation will propagate at a fairly slow rate for a period of time, and then suddenly propagate almost exponentially into a quick and sudden failure. Instead of having the linear separation propagation relationship which we observe in the case of a typical truck tire with good uniform strength, we will have a situation where we may see relatively slow propagation of separation over an extended period of time which then abruptly leads into sudden separation growth as the number of landings proceed. In a typical aircraft tire, we will see a small separation sit idly by, propagating very slowly as the number of landings progress, then all of a sudden it will propagate to failure over a relatively short number of landings. Aircraft tires are complex because the propagation mechanism is critically influenced by the overall structural strength or structural uniformity of the carcass. That is, a small separation in a weak carcass may propagate very fast, but a moderately sized separation in a very strong carcass will propagate very slowly and go through a surprising number of R levels before it will lead to a terminal failure.

The result in aircraft tires is that the stretch or the elongation as a function of applied load which gives us the most significant data, as opposed to the classical mechanics case for homogeneous metals where strain data which is measured as a function of applied stress, provides us with the best information. Life is basically simple in a homogeneous metallurgical situation, a one dimensional problem where you can pull on the material with a given applied stress in pounds per square inch and measure out the corresponding strain in inches per inch. Holographic testing does not provide us with strain data directly, but rather gives us the overall stretch or elongation characteristics of the carcass for a given applied load. This type of data turns out to be exactly what we need, since it reveals the general strength characteristics of the tire.

Briefly, we might note that holography is a laser photographic process which can photographically record a three dimensional view of the tire. Employing as a test method the combination of holography and interferometry, minute displacements can be measured in three dimensional objects. In the case of a tire system, it is absolutely essential to look at the complete three dimensional object, rather than gathering data at a single point which is the typical case for metals. In a tire, the comparison between relative rather than absolute data points is crucial to the strength of materials analysis. The

measurement of minute displacements in tires as a result of an applied load can lead to judgments about the quality of a tire.

Let us look at the following simple analogy which will help us to understand the manner in which we obtain the final data. Suppose we had a thinly stretched rubber membrane of which we had taken a three dimensional hologram. (A hologram is a special type of photograph taken with a laser beam.) We could then set up a very simple interferometer and look at that membrane after we had made the hologram. Then we could put our finger behind the membrane and push it very gently forward. The image that we would see as we push that membrane out would consist of rings or concentric circles which would be contours of constant displacement. As we push the membrane out, we could then generate a contour map (the contour lines on the map would represent levels of constant displacement or levels of constant heights above a reference) which would tell us the general displacement from the original position. Now in terms of a tire, we want to see the overall displacement between the unstressed and the stressed tire carcass. In reality, what we are trying to do is just set up a three dimensional stress-strain measurement where we can read the relative stretch or displacement out in the form of a simple image as a result of an applied stress. It is of crucial importance that we obtain our data over a region of the tire's surface as opposed to obtaining data at a single point in space which was the case prior to holographic interferometry. In a holographic tire testing machine, we take a photograph or a hologram of an interior region of a tire, say for example, a left to right view from 0° to 90° and a top to bottom view covering the tire from the top bead to the bottom bead as viewed from the center of the tire. If we take a second exposure on the same film plane of the interior of the tire after we have applied a stress, which can be done by putting the tire in a vacuum, we come up with a contour map that represents to us the stretch that is produced as a result of the applied stress.

To get the tire ready for testing, metal spreaders are put into the interior to hold the beads far enough apart to enable the camera to view the entire interior of the tire. The tire is then ready to be placed into the holographic machine on a merry-go-round turntable assembly under a vacuum dome. The tire surrounds the interferometric camera which takes the hologram. Ninety (90) to 120 circumferential degrees are automatically viewed at a time. The tire is holographed (or photographed) both with and without an applied vacuum to obtain the relative stretch caused by the applied stress. The tire is then rotated to the next 90 or 120 degree view, etc. Typical test time for a tire for the type of results we will be discussing is about two minutes.

In most of the tires which we test, we obtain an upper mid-sidewall to lower mid-sidewall view. In a few cases, we insert mirror assemblies to provide bead-toe-to-bead-toe views.

Now let us come back very briefly to the method. If you were to take an object and put it in a vacuum, that object being a multiple ply tire, the overall tire being tested would dilate, stretch, or elongate as a result of the applied vacuum. Our camera would record a background fringe pattern which would relate to us how the tire surface moves or stretches topographically.

In a situation where there is an interply separation inside the structure, not only do we get this displacement as a result of having put a negative pressure on the surface, hence lifting the entire surface; but there is also an added displacement as a result of the air expansion inside the void or interply separation. Whenever we observe the concentric ring pattern of a separation, it has a background fringe structure surrounding the separation which tells us the relative strength of that region, in addition to the fundamental pattern which reveals the void or separation itself. So, in summary, we observe a background displacement pattern as well as a displacement pattern which is associated with any separation, or lack of structural integrity.

Next let us explore this background pattern which reveals the general strength of the tire. For example, if we look momentarily at the turn-up region or the flipper edge of the tire and rotated the tire circumferentially (reference your observation point as being at the center of the inside of the tire) and assume that the tire's internal construction geometry remains the same within very close tolerances, as does the relative strength in that region; we will then note in the hologram that the fringe lines are always uniform and very beautifully behaved. If the geometrical components inside the tire are straight and geometrically symmetric, the fringe lines or contour lines will be geometrically symmetric. The tire has stretched uniformly due to the geometrically symmetric construction detail. In other words, the fringe lines merely correspond to the stretch nature of the tire. Had there been an interply separation in the tire it would have exhibited itself with its own characteristic pattern which is a direct measure of its given size. If the separation is close to the surface, with respect to the observer, there will be a larger bulge and consequently a larger number of fringes. If the separation is deep or farther away from the observer (near the tread), there will be fewer circular fringes or concentric circles. Consequently, we can resolve the general position of the separation in the structure as well as determine its relative depth in the tire. As you look from left to right, parallel to the bead, you will notice that the

fringes are extremely linear and horizontal. If you take a tire in your hands and rotate it around your head circumferentially (with your head at the center of the tire), wherever you look circumferentially (assuming you have X-ray vision), it should be the same geometrically. On the other hand, if you observe the tire in the radial direction, there are different cross-sectional thicknesses, different strengths, and therefore the fringe spacing is different. Hence from the above comments, all holographic fringes (aside from the pattern caused from changes due to variations in the index of refraction during the measurement which enhances the read-out) run horizontally from left to right and have different spacing up and down. Now what would happen if we had a tire where there were variations in the height, say at the turn-up? This variation could lead to a variation in the strength. Then instead of the classic very uniform linear horizontal fringes, we would see fringes which wander up and down as we move circumferentially around the tire. This would mean that we are getting a different magnitude of stretch as we move circumferentially around the tire.

When a tire is constructed with near perfect geometrical proportions and such exacting geometry is further coupled with near perfect adhesion throughout, the fringe pattern will be highly uniform. This happens because the tire carcass responds, stretches, or elongates due to the applied load or stress induced by the vacuum in a highly regular or uniform manner. In other words, if the strength of the tire is uniformly symmetric, the fringe pattern will be uniform. In a highly uniform tire, we find the separation rate propagating more slowly than in the nonuniform tires. Higher shear stresses as well as higher temperatures develop in nonuniform tires resulting in the higher propagation rates. For example, a quarter inch separation in a 40 x 14 aircraft tire will go through 200 or 300 cycles or landings before propagating significantly if it is in a very strong carcass. If, on the other hand, it is in a very weak carcass as revealed by nonuniform fringe contour lines, it may propagate to failure within 25 to 50 cycles, especially if it is in the shoulder region. If the background fringe pattern is geometrically nonuniform, cord tension will vary over a greater range and fatigue will set in much faster. Separations will evolve more readily and will propagate at a higher rate. If however, the background fringe pattern is uniform, separations will only rarely appear over the first hundred cycles; and when they do, they will propagate much more slowly. Hence in aircraft tires, it is particularly important to take this background structural uniformity into account when predicting the rate of propagation of a given separation at a given location. The performance characteristics of a given tire construction will be critically dependent upon the observed state of the tire's structural integrity.

In summary, it should be noted that a large structural uniformity data base must be established before a realistic acceptance-rejection criteria can be established on a given type of tire. The existance and size of a separation is not nearly as important an observation as the overall structural uniformity, unless of course the separation is well over an inch in diameter and it is in a critical geometrical position. One must always judge the criticality of the size of a given separation as a function of the observed carcass strength which is revealed by this general structural uniformity.

Now there are some basic questions at this stage which we should begin to ask ourselves. What is the incidence of interply separation in a typical sample of aircraft tires? Given the fact that they exist in a given structure, what is the probability of failure during the original tread life: R-0, or R-1: the first recap level, or R-2: the second recap level, etc. In general, there are fewer separations in aircraft tires than most of us realize. It turns out however in a few isolated cases, that abnormal outcropping of separations in given tire sizes do exist as a result of construction mistakes, poor workmanship, contamination, etc. Often modest changes in tire construction can reduce separation problems.

One of the most common causes of separation in new tires is due to the existence of pieces of "poly" left in the tire when these protective sheets are pulled off the original stock material during the building of the tire. An example of dealing with separation problems by changing construction details in 40 x 14's is to reduce cord diameter and increase skim coat thicknesses to provide greater insulation between plies. In one particular test carried out on 100 new 49 x 17 aircraft tires, the author found that 3% of the tires contained separations over one inch in diameter at the turn-up edge due to pieces of poly. The fact that at least one of these could have lead to a critical failure within its normal life expectancy is without a doubt.

But now let us come back to the basic point. Given the fact that separations do exist in aircraft tires, how many exist, and when they do exist in a given construction, how fast do they propagate? When and under what circumstances do they lead to failure? What is the proper time to take tires off of a given system so as to get the maximum usefulness out of a tire purchased?

To get a preliminary feeling for the answers to these questions, (a final answer is not yet possible), six descriptions follow of random samplings from a mixture of R levels taken from a few thousand aircraft tire tests. Let us choose first a random sampling (Sample #1) of 100 - 20 x 4.4 tires. About 9% of this sample were separated. Based on our data to this date, we would consider about 6% of that 9% to be moderately critical, implying that there is a given probability of failure within the life span of the carcass or more specifically, that there is a high probability that the tire would not pass a qualification test. Within this 6%, about 3% of the tires contained one-quarter inch or larger separations combined with poor structural uniformity such as nonuniform cord tension or fatigue. On the other hand as a comparison to this sample, the author has observed a group of 300, 20 x 4.4's in which not one single separation was found. Within this group, probably not more than one to three would fail the basic qualification test for the 20 x 4.4. However, we realize that the indoor qualification wheel test is undoubtedly more severe than the real world situation. In actual usage, all 300 of these tires would probably have lived out their full carcass lives over two or three R levels without mishap.

A more typical case (Sample #2) for 20 x 4.4's would be to find three to five seriously defective tires among a sample of 500, or about 1%. The percentage of critically defective tires in a given sample lot will vary significantly when testing tires manufactured by different companies. In other words, a much more significant variation in data appears when comparing different original tire manufacturers as opposed to observing different retreaders. The quality of tires also vary as a function of the date of manufacturers.

Next note a more typical random sample (Sample #3) in 30 x 8.8 tires. In this sample, of the one hundred tires chosen, only two were separated. And of those two tires, only one had a very high probability of premature failure since critical nonuniformity surrounded the separation.

Our next sample (Sample #4) is of 100 tires, size 40 x 14 - Manufacturer A. In this case, 41% of the tires were seriously defective and rejected, based on a rejection criteria for separations of 1/2" ± 1/4" or larger where the variation, ± 1/4", is a function of the overall strength of the carcass or structural uniformity. Most of the separations in the 41% were serious shoulder and/or splice separations. Less concern was given to the separations existing in the center or crown region of the tire as opposed to separations in the more critical shoulder regions. The ± 1/4" variation was used to single out strong and weak tire carcasses. In other words, a separation as large as three quarters of an inch inch would be allowed in a tire with a strong carcass, whereas a separation only as large as one quarter of an inch would be allowed in a carcass which was weak and fatigued. We should also note that a few tires in the 41% rejection criteria were rejected solely on the basis of extremely weak and loose carcasses; that is, carcasses containing no separations. We tested a number of these rejects (from the moderately-high-probability-of-failure types to the very-high-probability-of-failure types) on the indoor test wheel and they all, without exception, failed prematurely.

The questions, "What do you mean by critical separation?", or "How does one establish an acceptance-rejection criteria?", need to be answered. Acceptance-rejection criteria must be established on a very substantial data base; 100 tires is not substantial enough. After testing over 1000, 40 x 14's, we began to establish a good degree of confidence in terms of an acceptance-rejection criteria, which is 1/2" ± 1/4" where the variation of ± 1/4" as mentioned above is a function of the carcass strength. Now let us look at a sample of 100, 49 x 17's, which is Sample #5. Here, 11 tires were rejected. Although in this case we have not looked at enough tires to clearly establish an acceptance-rejection criteria, our general feeling is that separations up to one inch in diameter in the crown area are acceptable for an additional R level as long as the carcass is strong. However, only separations smaller than one-quarter inch would be tolerated in the turn-up area or shoulder areas.

Now let us digress momentarily to point out that the seriousness of a separation is established while observing, as a result of repeated tests through many R levels, the propagation rate of the separation as a function of the number of landings. In addition, the propagation of separation as a function of the number of taxi-take off cycles has been studied (the author has studied repeated tests on approximately 27 tires) on indoor test wheels. There is a desperate need for more indoor test data, since we have only scratched the surface of this immensely fruitful area of research. Furthermore, one establishes a very good feeling for how fast a separation propagates by observing from R level to R level how fast the tire is deteriorating both from the point of view of the structural uniformity and the structural integrity (the size of the separation as a function of the number of landings). By observing the increase in size of very small separations from R level to R level, one obtains a feeling or judgment as to how many landings a tire will go through before the separation reaches a size where the tire will fail. We have

observed both real world failures (failures on actual aircraft) in addition to failure cases which were simulated on indoor test wheels.

Next let us look at a larger sample (Sample #6) of 40 x 14's - Manufacturer B. In this distribution of 1000 tires, there is a total mixture between R-0's, R-1's, R-2's, henceforth, on up through the R-5 level. The basic distribution contained more R-2 levels than any other specific level. The rejection over the first 1000 tires based on our data base was 21.5%; however, these rejections were based on both separations and loose splice detail combined with overall cord looseness and tire fatigue. In other words, about 15% ± 3% of the total would be considered to be critical. And, in this case, we would define critical as meaning those tires which would have an above average probability of failing had the tire not been rejected prior to the next R level. A special note should be made that many of the tires we observed which contained critical separations were removed from service prior to failure due to cuts, skid burns, etc. Had the tire in the sample been more resistant to cuts, for example, the airline would have experienced even more than the typical one failure per month which was their situation. A brief note should be made that many of the serious shoulder separations which were in structural weak areas were not revealed by air needle injection.

A few additional comments might be in order with regard to the distribution of 100 new 49 x 17 tires. One percent, or one tire, contained a very critical shoulder separation which could have lead to a serious problem. Three percent, or three of the tires, contained crown separations with an average size of two inches in diameter. Separations of this size could lead to a problem previous to the next R levels. Five percent, or five tires, contained separations at the turn-up, flipper strip edge, and in the apex strip region above the beads. Another one percent, or one tire, exhibited very poor cord adhesion characteristics. Upon examining the eleven tires of special concern, we might note that tire #1 contained a crown separation over 1/2 inch. Tire #2 contained a 1" crown separation. Tire #3 contained a separation in excess of 1" at the turn-up. Tire #4 contained a separation in excess of 1" at the turn-up. Tire #5 exhibited cord socketing to an extent which could lead to a serious problem. Tire #6 had only a very small separation which would undoubtedly not lead to a problem. Tire #7 contained a 2" separation at the bead apex. Tire #8 contained a 1" separation at the bead apex. Tire #9 contained a separation in excess of 3" in the shoulder. This tire obviously had a high probability of premature failure - and soon. Tire #10 contained a 3" separation at the turn-up. Tire #11 had weak tread adhesion in general. The remaining 89 tires had a very low probability of failure and were excellent candidates for further retreading. It is important to note that all of these 100, 49 x 17's were new R-0's. Throughout the R-0 level, we would consider only one of these above eleven to have a very high probability of failure prior of the next R level; this tire being tire #9, -- the one with the 3" separation in the shoulder. Had any of the above eleven tires been overloaded and underflated at the same time at least five of the eleven would have had a high probability of premature failure.

Considering R levels beyond R-1, there now is a probability of failure which begins to become noteworthy even under normal loading conditions in tires #10, 3, 7; the tire containing the 3" separation at the turn-up, the tire containing the 1" separation at the turn-up, and the tire containing the 2" separation at the apex.

We should again ask ourselves the question, "What constitutes a critical defect?", that is, a defect which has a very high probability of failure prior to the next R level. And, how does one go about getting data which relates to defect criticality?

Allow me to digress momentarily to say that the beauty of truck tire testing lies in the fact that the data is so much easier to obtain. One simply sorts out defective truck tires from good truck tires, selects several hundred, and then mounts them on trucks in fleets with defective tires running along side good strong tires to minimize any possible danger of a serious situation occurring. Over ensuing months, and observations of many tire failures, it is easy to establish a clear cut criticality, or acceptance-rejection criteria. Such data can certainly be obtained in a one to two year period.

But, what can one do to establish criticality in the case of aircraft tires? First, one tests a very large number of tires and separates out those which have a lack of structural integrity (separations) and/or lack of structural uniformity (poor construction geometry, loose cord tension, fatigue, etc.). With aircraft tires, we cannot submit them to actual stress experiences as in the case of truck tires. Instead, we must sort out those tires having defects which appear to be of a critical nature and put those tires on an indoor test wheel to run them out to failure. After having done so, we must establish the basic rate of propagation as a function of the number of cycles or landings. The obvious problem lies in the fact that real world failure data is nearly impossible to obtain and the gathering of data on

an indoor wheel is slow and expensive. One researcher can direct a study on a thousand truck tires in the same period of time it takes to carry out failure analysis on 50 aircraft tires. Further work in this area is critically needed.

Before proceeding to a discussion of results on indoor test wheels to establish defect size criticality, it might be interesting to point out that in the case of a 40 x 14 tire, we made a mistake in the early stages of our testing and allowed a tire which contained a 2" separation to get placed into the "tires accepted" category as opposed to the "tires rejected" category. At that time, we were using an acceptance-rejection criteria of 1/2 inch. That tire, containing a 2" separation, was accidently mounted on an aircraft *and it failed on the fifth taxi-take off.* We were very fortunate in that the failure did not lead to a serious situation as it could have. As a result of this experience, we believe that a 2" separation would obviously go to failure very quickly.

But what about the case of the 1/4", or 1/2", or 3/4" separations? How soon would they fail? Our next step was to take these types of separations to the indoor test wheel and to observe their propagation as a function of the number of cycles. (However, it is not always necessary to go to the indoor wheel.) As our first example of the indoor test wheel, we will look at a 40 x 14 - 21 tire and observe the increase in the separation diameter propagation as a function of the number of taxi-take off cycles. In this first case, we observed in the original carcass a 7/8" diameter separation. The tire was then mounted on the indoor wheel and after a brief warm-up period, the tire was cycled through five taxi-take off cycles. The tire was then taken off the test wheel, dismounted, and then reholographed. At this time, we observed that the 7/8" diameter separation had grown to 1-1/2" in diameter. The process was repeated for another five taxi-take off cycles and the 1-1/2" diameter separation had now grown up to 6" in diameter. Other separations had grown in diameter which were close to the original 7/8" diameter separation. These separations, as they had grown, had also joined up into the above mentioned 6" diameter separation. Again, a 1/8" diameter separation in this same carcass, which was originally close to the previously mentioned 7/8" diameter separation, grew after five cycles to a 3/4" separation. Then after having had the process repeated, grew from a 3/4" separation in an additional five taxi-take off cycles up into the 6" separation mentioned earlier. At the same time, an original 1/2" diameter separation, which was at a further distance from the original two separations mentioned, after five taxi-take off cycles had grown to 1-1/4 inches. Then after another five taxi-take off cycles had reached out and joined into the above mentioned 6" separation. In other words, the original 7/8" diameter, 1/8" diameter, and 1/2" diameter separations all grew significantly and finally ended up after ten taxi-take off cycles in a single 6" diameter separation which then, in turn, went to failure after six additional cycles.

Let us give an additional example in a 40 x 14 - 21 aircraft tire. In this tire once again, there was a considerable lack of structural uniformity throughout. In this case, a 1/2" diameter separation in the original measurement propagated to a 1-1/2" diameter separation after five cycles which, in turn, propagated to a 5.5" diameter separation after yet another five cycles. Another original 1/4" separation propagated to 1/2" in diameter after five cycles which, in turn, propagated to 4" after five more cycles. So, therefore, we note that separations in the 1/4" to 1/2" category propagate quite quickly, particularly when they are in a tire which is structurally weak and/or the separation is in a shoulder region as the above cases were.

Next, allow me to give four examples of propagation of separation in aircraft tires - size 26 x 6.6. Due to the shortness of this paper, our examples of this propagation will be brief. In the first, on 26 x 6.6's, a 1/4" separation at 127° in the crown area of the tire propagated to a 1/2" separation after five cycles which, in turn, propagated to 5/8" after five more cycles, which in turn propagated into a 5" separation after yet another five cycles. An original 1/4" separation at 143° propagated to 1/2" after five cycles, and then propagated to 3/4" after yet five more cycles, and finally propagated into the 5" separation mentioned above after five more cycles. A third separation at 153° in the crown which was 3/4" in diameter propagated to 7/8" in five cycles, which in turn propagated to 1" in five additional cycles, which in turn joined into the above mentioned 5" separation. The 5" separation then, in turn, failed after four more cycles. From the above, we note that separations ranging from 1/4" to 3/4" propagate quite rapidly as a function of the number of cycles. Moreover, these individual separations have propagated this quickly as a result of the fact that they were clustered quite close together. Had these separations been further apart, or had they existed singularly, they would not have propagated as fast.

Next let us look at an example of a 1" separation in a 26 x 6.6 tire. This separation propagated after five cycles into a 2" separation which, in turn, after five more cycles propagated into a 4" separation which, in turn, propagated to failure at the beginning of the sixth cycle.

Another description is of a 26 x 6.6 tire which had a very weak carcass. This tire originally had a separation, 3/8" in diameter, which propagated to a 5" separation in five cycles which, in

turn, propagated into a 12" separation in five additional cycles which, in turn, failed before the next cycle was completed.

Next allow me to provide a brief example of a tire which showed extreme nonuniformity in weakness throughout the carcass, but contained no separation initially. It exhibited the fact that a tire which had extreme amounts of fatigue and structural nonuniformity would develop separations very quickly. In this case, after five cycles a 1/4" separation evolved at a specific point. This 1/4" separation in turn propagated to a 2-1/2" separation within five additional taxi-take off cycles which, in turn, propagated to a 20" separation after five additional taxi-take offs.

This type of data could be given in great detail for a large number of examples, but it represents the typical type of information that one obtains on an indoor test wheel. Needless to say, high quality "control tires," observed holographically, ran beside these without mishap. (In a number of cases, as an aside comment, we have predicted the success or failure of tires being sent through conventional qualification tests required by the Navy.) In summary, we can say that when separations exist in a 26 x 6.6 aircraft tire in the size category of 1/2" ± 1/4", they will propagate to failure in a surprisingly short period of time especially if the carcass has poor structural uniformity (low adhesion levels being one of the more critical situations in the 26 x 6.6's). On the other hand, if a separation exists in the 1/2" ± 1/4" category, it will go through a significantly larger number of cycles (25 to 50) before it goes to failure if the carcass possesses a high degree of structural uniformity. Rather than give a large amount of data in this short paper, the author is presently preparing a publication which provides more detailed information on separation propagation as a function of the number of taxi-take off cycles on indoor test wheels.

Before proceeding, mention should be made about the percentage of rejections as a function of a given R level for commercial aircraft tires. We have found throughout our statistics that roughly speaking the same percentage of rejections plus or minus 10% take place at each R level in large distributions of 40 x 14 - 21 aircraft tires. This data would suggest that separations are appearing at each R level at about the same rate. Separations continue to appear as the cords loosen up and general fatigue sets in. Much of the data which we have observed to date in 40 x 14's would suggest that one would be wise not to make the decision to reject a tire based on a given R level. It would appear to be a much wiser criteria to decide on the life of a tire based on the number of cycles or landings it goes through rather than the number of R levels. This is the data which must be obtained in the future. We strongly feel at this time that once an understanding is obtained of the degradation of a carcass as a function of the number of landings, decisions should be made wherein a tire is allowed to stay on an aircraft as a function of the number of landings and not as a function of the number of R levels. It is conceivable that a tire with a R level of, for example 5 or 6, could have significantly less landings on it than another tire which is only an R-2 or R-3. This could partially explain the reason why we sometimes see less fatigue in an R-5 or R-6 than we might in an R-3 or R-4.

Next we note in terms of the failure mechanism characteristics of a given tire construction that the small separations propagate very slowly if they are in a very strong tire and that these separations will propagate out through a number of R levels before the background carcass begins to weaken, to loosen up, and then go to terminal failure over a fairly short number of cycles. Now let us compare the above notation very briefly to truck tires whose separation propagation rates are well behaved. If we were to look at separation size as a function of mileage and draw a graph for truck tire data, we would notice that it would fall very nicely along a given line. In general, the relationship between separation size and mileage is a linear function with the variation in slope of that line being determined by the overall strength of the tire. In the case of truck tires, we then have a band of linear traces whose milder slope represents tires which are quite strong. Those linear traces with a stronger or higher slope represent tires which are weaker.

When measuring aircraft tires, we think in terms of the number of taxi-take off cycles versus separation size. Here, we notice that a small separation will typically propagate in a strong tire slowly wherein the curve along which it travels (that is the separation diameter as a function of cycles) will look very much like the truck tire case. After many cycles, and after the carcass has begun to fatigue and loosen up, there will be an increase in separation size as a function of cycles which will increase exponentially to the terminal failure point. In a tire which has a very weak carcass, we will note that the separation size will increase exponentially as a function of the number of cycles in very early stages whereas, as mentioned above, the separation size as a function of a number of cycles will increase linearly with a very mild slope for a long period of time and will then rise exponentially in a strong tire. As mentioned earlier, the cardinal difference between truck tires and aircraft tires is the following point. Almost without exception, all separations or areas with a high probability of separation will be observed in the original

carcass at the time the tire is new. Even after the tire has been retreaded, new separations are unlikely to appear in a radial truck tire unless they are the result of mistakes the retreader has made. New separations which are specifically a function of the carcasses themselves do not appear at these later stages. Conversely, in the case of aircraft tires, the separations which are observed at various periods during the life of a given aircraft tire carcass seldom appear when the tire is new or straight out of the mold. As a matter of fact, on the average, rarely does one see in new aircraft tires more than 1% or 2% which are separated. On the other hand, after a number of cycles, perhaps 1000 landings, which may be at a R-5 level, one might note a number of separations in a given tire carcass which did not appear either at the early stage of the tire's life, or in the previous R level. In other words, separations continue to form and propagate at a variety of stages throughout an aircraft tire's life (throughout each of its R level stages). It is not uncommon to see no separation in a R-0 level of a given tire, or its R-1 level, or its R-2 level and on up to some R-n level whereupon separations will appear over a very short period of time and with great profusion. When establishing acceptance-rejection criteria, this would lead one to the conclusion that aircraft tires must:

(A) be studied to determine the type and location of separation which will form and the average rate of propagation of these separations. The rate of propagation is by far the most significant parameter for a given tire.

(B) be studied to determine the type of failure mechanism which a given construction experiences. Furthermore, it is evident that the tire must be tested intermittently after a given number of landings. In the case of 40 x 14 - 21, the number of landings associated with a given R level for example from R-1 to R-2 in a typical DC-9 operation, turns out to be just about the ideal spacing for the frequency of testing.

(C) be studied by holography before and after each R level to determine the optimum number of landings for a given size, construction, and manufacturer. In the future, this test time can be established as a function of the number of landings a tire experiences, provided that the inflation pressure has been maintained throughout the period under consideration. Note: underflation will significantly increase the propagation rate of separations. If a tire reaches an established number of landings, it should be retested prior to further use.

The following information is the result of our first commercial carrier studies which were carried out over the past two years. This carrier was experiencing approximately one tire failure per month over a one year period with an average cost per failure (amortized over the year) ranging between $20,000 and $25,000, due to structural damage to the aircraft and rubber ingestions in the engines. Over a relatively short period of time, all the tires in service of a given type were holographically tested and all tires with separations greater than one-half inch in diameter were rejected. Since the tires with separation over one-half inch were taken out of the systems no tire failures were experienced over the following two years. It is important to note that this type of testing will not eliminate all tire failures, but it can significantly reduce the incidence of failure which has been dramatically proven in more than one airline. It is interesting to note that the original rejection rate in the above case was slightly over 20%, whereas after culling out the tires containing separations over one-half inch in diameter, the rejection rate fell to around 12%. Further analysis has revealed that larger separations can be tolerated in the crown area which puts the rejection rate under 10%.

Now to summarize. The basic objective of this talk has been to comment upon the meaning of separations in aircraft tires. You can look at a large distribution of tires and discover, as Mr. Shaver, the Engineering Vice President of Air Treads, Inc., has pointed out so aptly and carefully, "large distributions of tires have very low incidences of separation - at times as low as 1%." Then we will note other case histories, where the percentages can get significantly over 10%. Our basic objective at this time is to understand more thoroughly the background strength criteria in aircraft tires and to establish an acceptance-rejection criteria based on a fairly large data base. In general, we would like to test 1000 tires in a distribution and then cull out those tires which have separations. The tires pulled out must be evaluated to determine separate propagation rates as a function of structural uniformity. Acceptance-rejection rates should then be established and then routine testing of the tires should be carried out at each R level where the R level does not exceed a given number of landings for a given tire size and construction. It has been said, "Well, you see most separations in retreaded tires; you don't see many of them in new tires." This is a misleading point. Although separation does not exhibit itself until an advanced stage in a tire's life, the original construction and the care with which the original tire is built has a significant impact on the amount of separations which will appear in the tire's later life. Needless to say, we find that retreading practices are not often the cause of separation in aircraft tires.

It is only going to be with the greatest of effort and patience that the separation propagation rates

and basic failure mechanisms are understood whereupon realistic acceptance-rejection requirements can be placed on a given tire despite the fact that relatively few tires contain separation. Although all tires experience fatigue as a function of usage which will, in turn, eventually lead to separation, the general performance of the typical aircraft tire far exceeds that of most typical engineering systems. Aircraft tires perform an extraordinary job in terms of the requirements that are placed on them and the abuse given to them. With some modest effort, great improvements can be made at relatively low costs resulting in an example of one of the most impressive engineering systems of our day - namely the typical run-of-the-mill aircraft tire.

QUESTIONS - deleted at author's request, Editor

ARMY PROGRAM IN NDT OF TIRES

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The Army program in NDT of Tires is directed for the most part toward retreaded military truck tires because the Army retreads over one-half million tires each year under a mandated materials conservation effort. While many tires are retreaded at Army facilities, a large percentage go to local procurement. Thus, the Army interest in equipment development is first directed to the very start of the retread cycle: determining carcass integrity to sort the carcasses before they reach the buffers of either Army or civilian facilities.

The second major Army interest is generated by the nature of tire usage and procurement that is probably peculiar only to the vast fleet of the Army. Because of the large number of mounted and unmounted tires in the fleet and in supply channels, and because so many vehicles receive minimal use over extended periods, there is considerable aging and general deterioration of the tires. So that we will have a true picture of our operational readiness, a continuing study is being made to learn how much of this degradation can be appraised and how much is significant to tire life expectancy. Elaboration on these two areas will be made in the four papers that will follow and which will report the in-house and contractual efforts that are currently under way in support of the Army's program in NDT of tires.

NONDESTRUCTIVE MEASUREMENT OF CASING QUALITY

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INTRODUCTION

The large volume of tires used on DoD vehicles necessitates an extensive retread program within DoD (and especially within the Army). A simple, low cost, reliable method of determining the integrity of a tire casing prior to the retreading operation is very desirable. The Product Assurance Directorate (AMSTA-Q) and the Maintenance Director are (AMSTA-M) of the Army Tank Automotive Command are co-sponsoring a program to develop such a method. There are several nondestructive inspection methods presently being applied to tires: X-radiography, infrared, holography, and ultrasonics. All of these methods are capable of detecting defects in tires. However, on analysis, ultrasonics seems to best fulfill the Army requirements of low cost and simple application.

There are a number of ultrasonic techniques useable for this application. Both thru transmission and pulse-echo were evaluated. The inherent mechanical simplicity of a single transducer pulse-echo system, its depth discrimination capability allowing a casing evaluation independent of tread presence or thickness, and its ability to provide on-vehicle, wheel-mounted, tire inspection made pulse-echo our choice as an inspection tool.

INSPECTION SYSTEM

A retread - production - oriented, ultrasonic pulse-echo inspection system was developed for the Army to check the method's practicality. It incorporates the transducer positioning requirements to inspect a range of tire sizes (7:00 x 16, 9:00 x 16, 9:00 x 20, and 11:00 x 20). The system has power tire mounting and rotation features, and incorporates a modified commercial ultrasonic inspection unit.

The inspection system developed is shown in Figure 1. Briefly, it contains an immersion tank necessary to couple the high frequency ultrasonic energy into the tire, the transducers and fixturing required to inspect the tire sizes mentioned, and mechanical equipment to simplify the handling. Figure 2 shows three transducers mounted to a fixture which permits setting of transducer angle for the various tire sizes to be inspected. We inspect the mid-line and shoulder areas of each tire. The tire handling equipment is shown in

Figure 1. Ultrasonic tire inspection system.

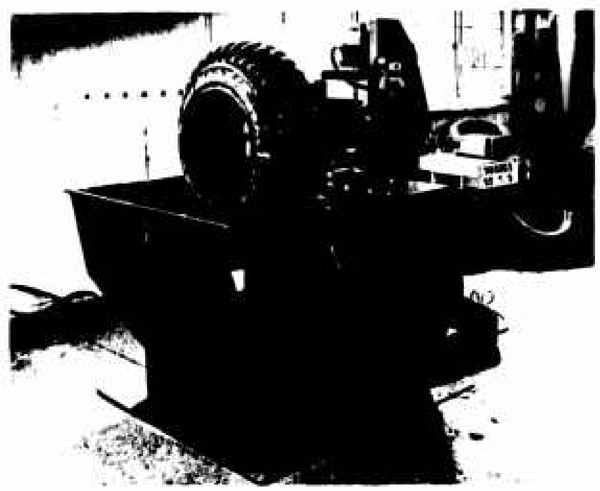


Figure 2. Transducers and holding fixture.

Figure 3. It consists of a modified Branick Tire Spreader, a pneumatic lift table, and a rotary bearing to allow the tire to be placed in the tank.

The tire handling procedure is straightforward and is made with production inspection in mind: mounted onto the spreader, it is lifted above the water tank walls, rotated 90 degrees, and lowered into the water tank. The tire is then ready for ultrasonic inspection. The procedure is reversed to remove the tire from the system.

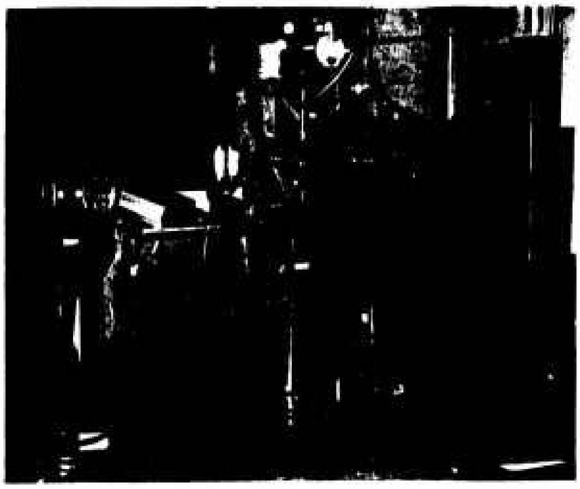
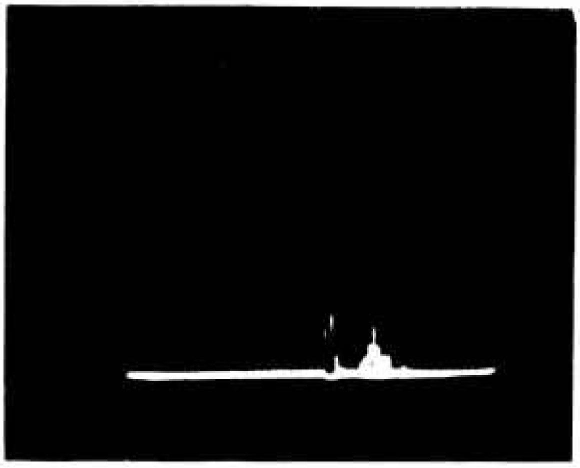
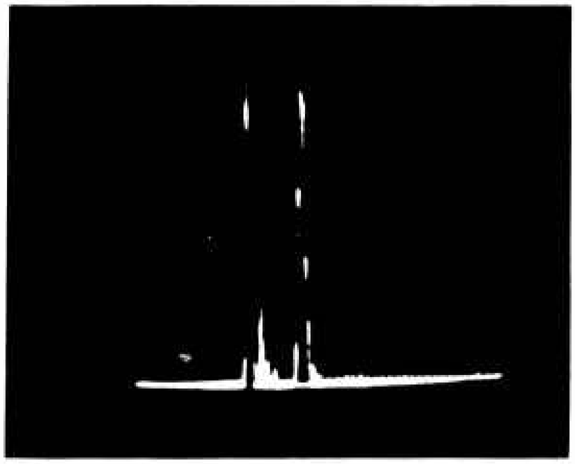


Figure 3. Tire handling equipment.



a. Tire which does not contain a defect.



b. Tire with a defect.

Figure 4. Ultrasonic tire defect detection.

The ultrasonic instrument has an automatic audible alarm system which tells an operator of the presence of a defect.

Figure 4 is a recording of the instrument's oscilloscope trace. The recording in Figure 4a shows the ultrasonic pattern from a tire which does not contain a defect. The photograph in 4b shows the ultrasonic pattern which has a defect. Figure 5 is a photograph of this defect which was found by automatic alarm inspection. The defect is a break about 3/8" deep. It extends through the outer breaker belts and into the first outer ply layer. This type of defect would not be found during buffing. An example of the other type of defect defected ultrasonically and confirmed by buffing is shown in Figure 6. It is a typical tread/ply separation in the shoulder of the tire.

TESTING

In order to determine the adequacy of the system developed, it was necessary to develop statistical data on the type, number, and location of detectable flaws in tires. A tire testing program was, therefore, conducted. Four hundred-fifty tires were inspected.

DISCUSSION

Figure 7 summarizes the results of the inspection. Comparison of ultrasonic test results with optical examination and physical test data confirmed that six percent of the tires had what can be described as localized defects (nail holes, separations, breaks, etc.). Forty-six percent had what can be described as circumferential defect indications (defined as a general deteriorated condition around most or all of the circumference of the tire).

Sixteen percent of the localized defects (1% of all tires tested) consisted of inclusions or breaks. Eighty-four percent (5% of all tires tested) consisted of either cord or ply separations. Sixteen tires which presented localized ultrasonic defect indications were sectioned and examined. Visual confirmation was obtained for each of the ultrasonic indications.

Forty-six percent of the tires inspected had circumferential defect indications. Fifty percent of the circumferential defects (24% of all tires tested) were found to be associated with low tread bond, 22% (10% of all tires) were cord separations or outer ply deterioration, and 28% (12% of all tires) were loose cords. Twenty tires exhibiting circumferential ultrasonic inspection indications were sectioned, visually examined, and subjected to peel test.

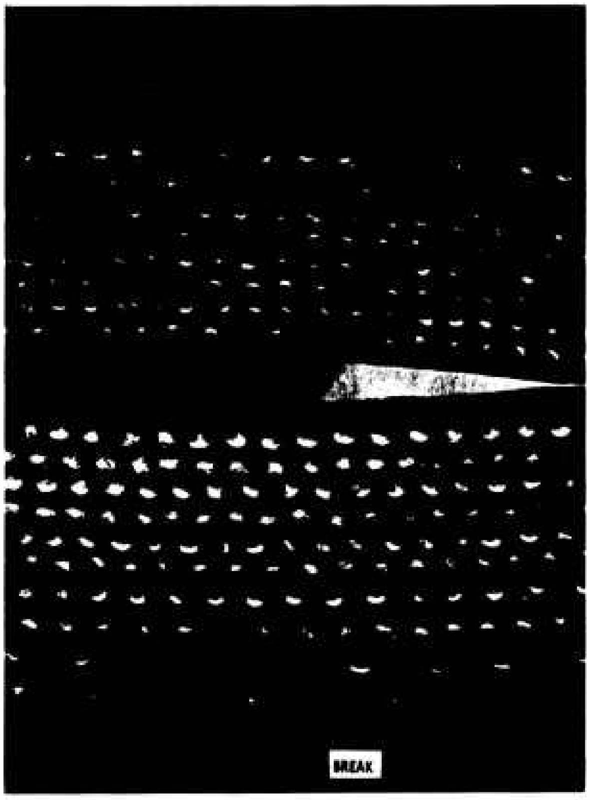


Figure 5. Cross section of break detected.

In summary, correlation of mechanical and visual test results with ultrasonic inspection data (from Military tires) had demonstrated three significant items:

(1) Localized defect occurrence is small;
(2) circumferential defects are significant in number; and
(3) ultrasonics can find both.

The first two, together, indicate that the prime Army emphasis heretofore placed upon the detection of localized tire defects may be misplaced. As a result, our current research is directed primarily towards evaluation of casing quality based upon general tire state of degradation.

DEGRADATION MEASUREMENT

An analysis of the ultrasonic signals, microscopic observations, and peel test properties indicated that a relationship exists between reflected circumferential ultrasonic signals from tire plies and casing degradation.

Visual observation has shown that certain ultrasonic reflection signals are associated with strong interply adhesion and tight cords; other signals are correlated with loosening of the

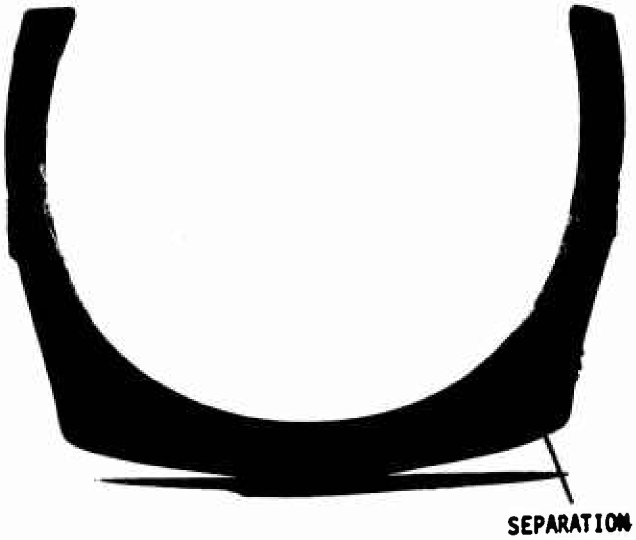


Figure 6. Tread/ply separation detected.

INSPECTION	INDICATION OCCURRENCE	DEFECT	DEFECT OCCURENCE
LOCALIZED	< 6%	INCLUSION BREAK	< 1%
		CORD SEPARATION PLY SEPARATION	5%
CIRCUMFERENTIAL	46%	LOW TREAD BOND	24%
		CORD SEPARATION OUTER PLY DETERIORATION	10%
		LOOSE CORD	12%

Figure 7. Inspection results.

rubber-cord matrix; still other signals indicate total matrix degradation. Figure 8 shows cut tire sections having a) loose cords and b) matrix separation. These conditions can be ultrasonically segregated from each other and from a tight matrix of a new or little used tire.

It was assumed, that as a tire casing goes through its useful life, it "degrades" (i.e., the cord-rubber matrix transforms from tight to loose to separated). Thus, an instrument which could monitor such progression could predict remaining useful life of a tire casing.

To evaluate this theory, tires being road tested at the Army Yuma Proving Grounds were monitored. Figure 9 shows that actual mileage on tires were monitored by this ultrasonic technique. The curve represents an average of many tires while the vertical drop at 6000 miles represents either damage caused during retreading or the uncertainty about the retread level of the tires.

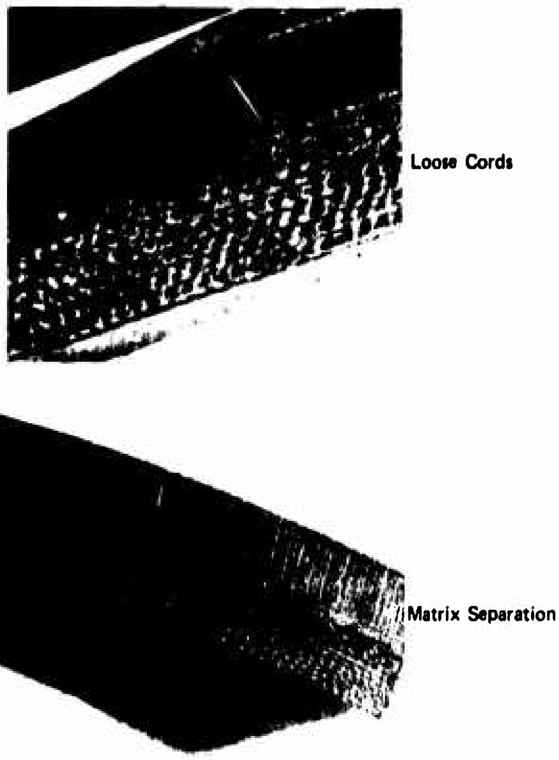


Figure 8. Tire degradation stages detected ultrasonically.

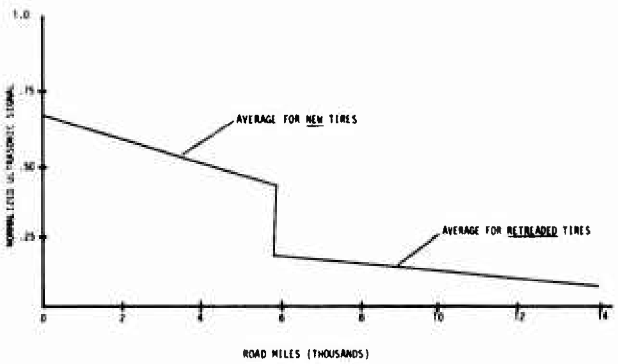


Figure 9. Preliminary road test data.

Figure 10 shows an actual on-vehicle tire degradation measurement being performed at Yuma. As can be seen, it is performed with a portable instrument using hand contact of the sensor. The inspection time per tire is about one minute. Initial results with the technique have been favorable enough that GARD is currently under contract to the Army to develop quantitative data for incorporation into maintenance procedures to establish accept/reject criteria for retreadability of tire casings based upon retread and new tire costs.

For those who may be interested, we have a demonstration of the technique set up upstairs. We are anxious to explore the commercial possibilities of this equipment and we will welcome your comments and suggestions. We have no reason not to believe that commercial truck and passenger tires behave in the same manner as military tires. In fact, we have limited data on passenger and truck tires which tend to confirm that they do behave similarly. We intend to pursue this area further during the coming year.

Figure 10. On-vehicle tire degradation measurement.

QUESTIONS AND ANSWERS

Q: How much does a commercial unit cost?
A: We're currently trying to figure out how many we can sell, but I think the range we're talking about is $5000, maybe $6000, depending on how many we think we can sell. I think the important thing to stress here is the reason this unit might be less expensive than most of the other units. We do not feel a need to go to the mechanical handling that you need when you look at ply separations. Frankly, the electronics and so on may be roughly comparable in all the different techniques.

ULTRASONICS VERSUS ROAD TESTING

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INTRODUCTION

From the period of July 1974 to May 1975 the Product Assurance Directorate of the U.S. Army Tank-Automotive Command (TACOM), Warren, Michigan, conducted tests to compare the wear characteristics of new and retreaa tires.

Three tire sizes were used for the test. These were the 700 x 16, 900 x 20, and 1100 x 20 non-directional cross-country (NDCC) bias ply tires. These three sizes have the highest density in the Army system.

The test was conducted at Yuma Proving Grounds, Yuma, Arizona. This site was chosen because of its severe climate and terrain, probably the worst conditions to which a tire can be subjected.

In conjunction with the wear test, the tires were evaluated using ultrasonic inspection techniques developed by TACOM's Product Assurance and Maintenance Directorates. The objective of the ultrasonic evaluation was tc provide statistical data on the condition of the retread bond line and tire cords and to relate this data to tire performance.

SYSTEM DESCRIPTION

The ultrasonic test equipment, used to nondestructively inspect the tires in the test at Yuma Proving Grounds, consisted primarily of an ultrasonic transducer, used to transmit and receive ultrasonic pulses and a cathode ray tube scope, used to display the reflected sound waves.

The ultrasonic inspection technique employed is the pulse-echo method. Using this method, an ultrasonic beam is transmitted into the tire at the ply layers, the beam is reflected and the echo is received by the same transducer used to transmit the beam. A schematic of the pulse-echo process is shown in Figure 1.

The various tire interfaces that produce signals on the scope and their corresponding background signals are shown in Figure 2. Figure 3 illustrates the various scope displays that can be encountered while inspecting tires using ultrasonics. The normal condition implies that the tire is basically sound, with no ply separation

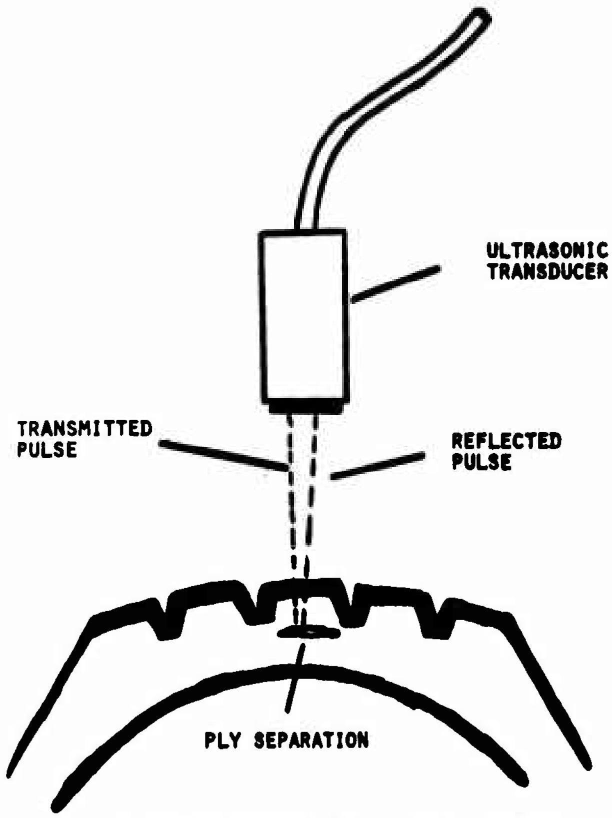


Figure 1. Pulse echo method of ultrasonic tire inspection.

or degradation. A low signal indicates loosening or unraveling of individual cords. The high signal (spike) indicates separation of the cords from the surrounding rubber. These various conditions are illustrated in Table 1.

INSPECTION PROCEDURE

For the Yuma test, a contact inspection method was employed. In this method, the transducer is in direct contact with the tire coupled through a thin film of oil and water.

Each tire was inspected along the centerline for approximately fifteen inches around the circumference of the tire and approximately four readings were taken and averaged. The following data was recorded for each tire: Tire size, cord material, background level, bond-line level, date of

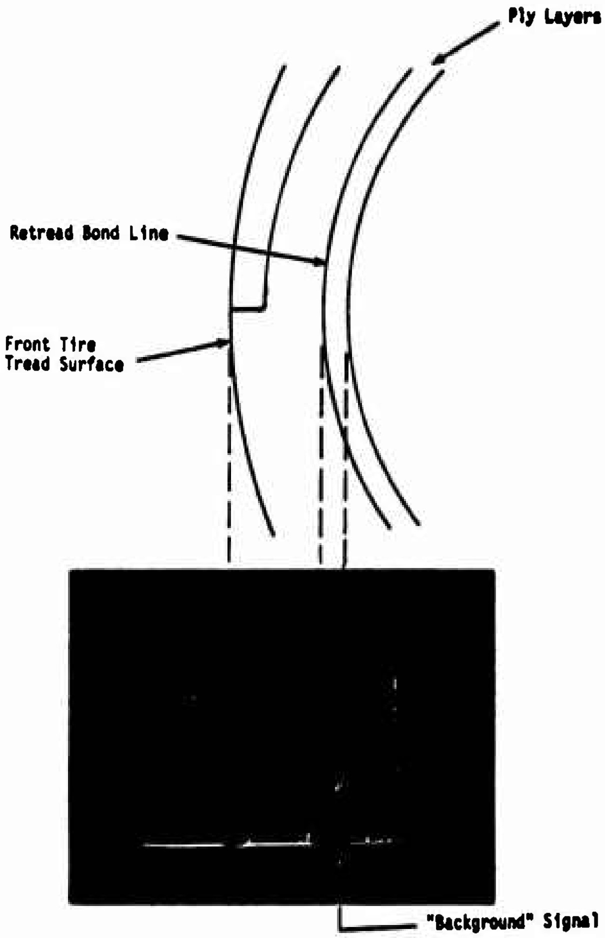
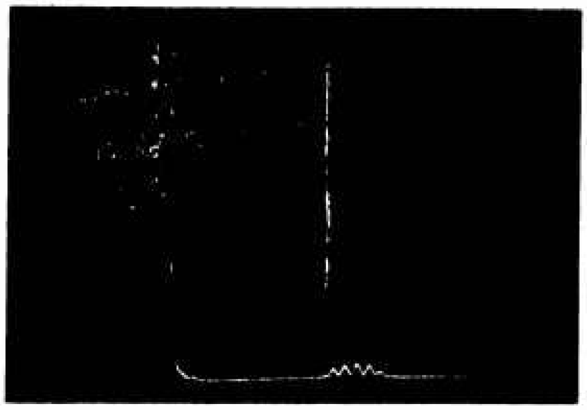


Figure 2. Schematic of tire interfaces.


"Normal" condition


"Low" condition

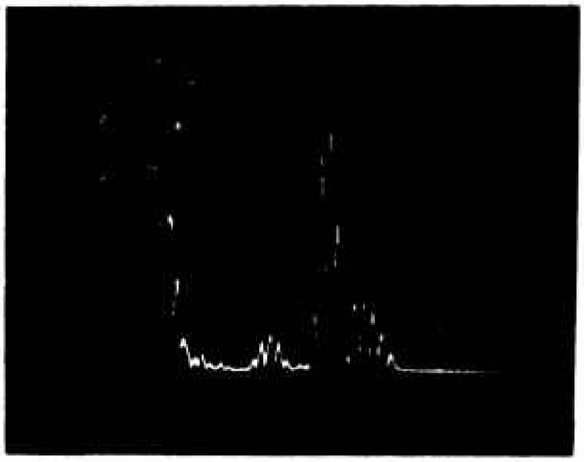

"High" condition

Figure 3. Typical ultrasonic ply background A-scan presentation.

manufacture, original manufacturer, tire test code number, new or retreaded tire, position on the vehicle, test miles, and cause of test termination.

INSPECTION RESULTS

The following analysis of the ultrasonic test data is centered around the 1100 x 20 retread bias-ply tires. This is due to the fact that more pertinent data is available for this size than for the 900 x 20 or the 700 x 16, because the ultrasonic test equipment was not available at the beginning of their testing, thus readings were taken only upon test completion for the latter two sizes. However, examination of the after test readings for all three sizes indicates a high degree of correlation, which would indicate that the results obtained in the analysis of the 1100 x 20 data is representative for the 700 x 16 and 900 x 20 size tires. Figure 4 shows the high degree of similarity between after test readings for the three sizes of tires.

Table 1. CASING DEGRADATION INDICATION

CORD/RUBBER MODEL			
CORD/RUBBER CONDITION	NORMAL	LOOSE CORD	CORD SEPARATION
ULTRASONIC SIGNAL (IDEALIZED)			
ULTRASONIC CLASSIFICATION	NORMAL	LOW	HI
PEEL STRENGTH	100%	90%	65%

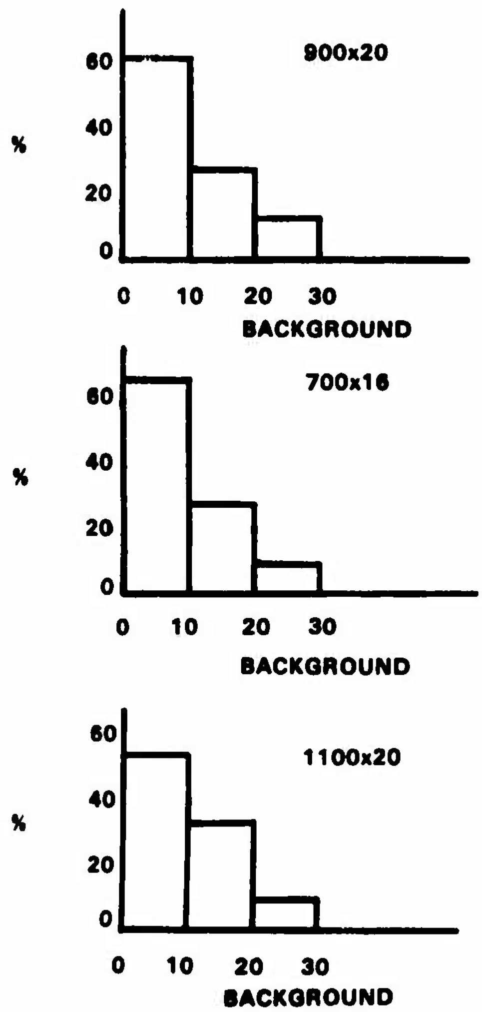


Figure 4. Percentage of total population versus ultrasonic background reading after test.

The first step in the analysis was to relate the ultrasonic background readings to the total test population of 1100 x 20 retread tires. Figure 5 shows the population density of the test tires with regard to their ultrasonic background readings. A majority of the tires were in the 10 to 20% range before the test started, however, the significant indicator of degradation lies in the fact that when the test was completed all 40 to 50% readings had disappeared.

A life cycle curve or "map" for the 1100 x 20 tires is shown in Figure 6. This map illustrates the degradation with occurs in tires as they run to failure. The points were obtained by plotting average background readings versus average mileage. Segment 1-2 represents the degradation which occurs in new tires as they are run to failure or wearout. Segment 3-4 represents the degradation occurring in

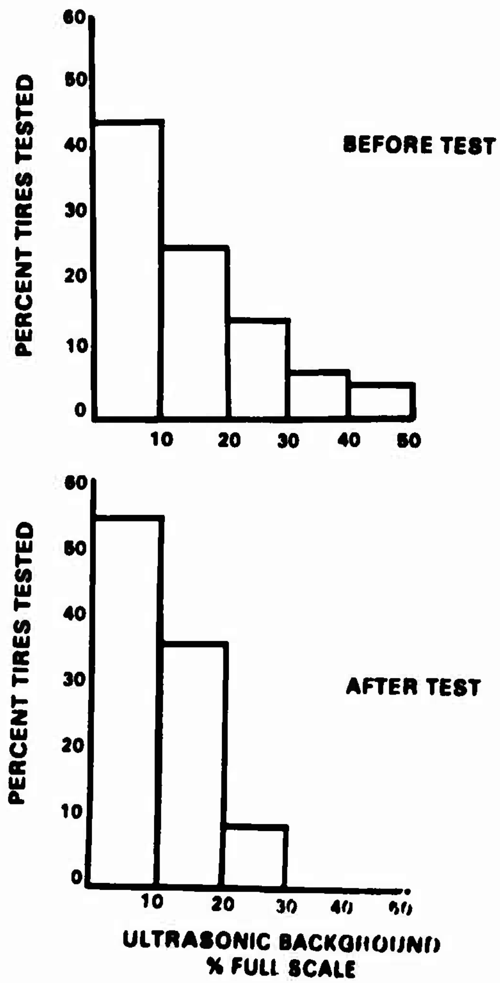


Figure 5. Percentage of 1100 x 20 retread tires versus ultrasonic background reading.

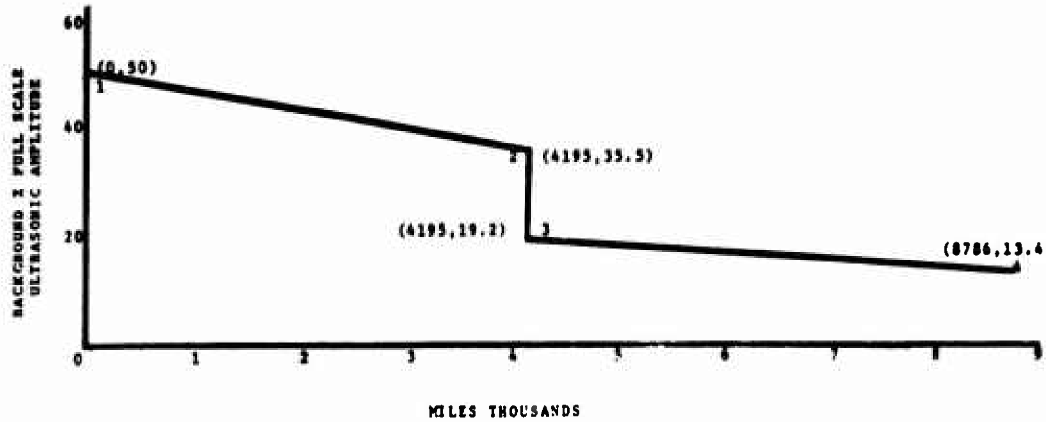


Figure 6. 1100 x 20 tires average background reading versus average mileage.

retread tires. The most revealing portion of the graph is the vertical drop shown by segment 2-3. This drop represents degradation during the retreading process. However, this drop is not as drastic as shown in the graph due to the fact that points 2 and 3 are mutually exclusive (i.e., the tires used to determine point 2 are not the same tires used for point 3) and the fact that experimental error was introduced because the retread level of the tires was unknown (a second or third retread would have a much lower reading than the first).

Of the total population of 1100 x 20 retread tires checked ultrasonically, 63% failed during the test. Figure 7 shows this failure data plotted versus the ultrasonic readings taken prior to testing. This is shown as the probability of wearout (i.e., success). As the amplitude of the background signal increases, the probability of reaching the wearout point increases.

CONCLUSIONS

The results of the ultrasonic portion of this tire test showed that:

a. Tire cord condition (i.e., degradation) can be measured.

b. The pulse-echo technique can be used to evaluate the internal changes in a tire due to retreading.

c. The condition of the bond between the retread cap and tire casing can be evaluated.

From the data, it is concluded that ply separation alone cannot predict remaining tire life. Instead, the condition of the tire cords (degradation) and in retread tires, the condition of the retread bond line, are the indicators of expected tire life.

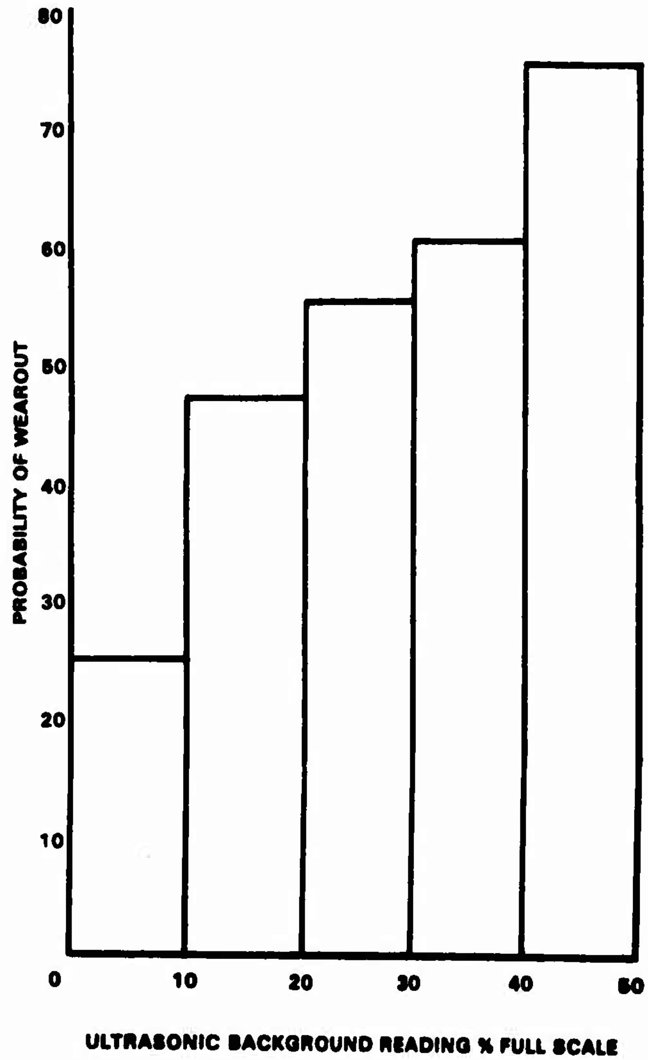


Figure 7. Probability of wearout versus ultrasonic background reading.

HOLOGRAPHICS VERSUS ROAD TESTING

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The Army conducted a tread wear test of its more widely used truck tire sizes at the Yuma Proving Grounds from July 1974 through May 1975. Yuma was chosen because it was felt that the conditions there were some of the severest that can be found. It should be noted that our study placed emphasis primarily on the retreaded tires that were tested. It is from the retreads, the Army feels, that the greatest benefits from nondestructive testing can be obtained. The sizes tested and the vehicles on which they were placed were: the 700 x 16 tire, used on the jeep; the 900 x 20 tire, used on the 2-1/2-ton truck; and the 1100 x 20 tire, used on the 5-ton truck. The test consisted of four 3000-mile cycles for the jeep and four 5000-mile cycles for the 2-1/2-ton and 5-ton trucks. The cycles were divided in the following manner; 60% paved road, 20% secondary roads, and 20% cross-country roads. Various loading conditions were placed on the vehicles with lighter loads being placed on the cross-country portion of the cycles. Every tire tested was first examined holographically. After testing was completed, a second hologram of the tires was taken. The data obtained from each hologram was placed on a data sheet and graphs of population versus the number of defects were produced from these sheets. From these graphs it was hoped that trends would develop to predict the life obtainable from an examined tire.

A commercial holographic tire analyzer, the GCO-AT-12, was used to examine the tires at Yuma. The examination process of the test tires begins when a tire is spread by mechanical fixtures in order to observe the inside of the tire. At atmospheric pressure a quarter section of the inside of the tire is illuminated by a laser light and a photograph is taken. The tire is then subjected to a vacuum and a second photograph, actually a double exposure, is taken. The vacuum creates a stress which causes a very small displacement of the inner surface of the tire in the area of a void or separation which results in a fringe pattern on the holographic film. The result of these two exposures of the same area under different stress levels is a single holographic picture of hologram. This process is repeated until all four quarters of the tire have been holographed. By reilluminating this hologram with laser light in a holographic reader, defects under the surface of the tire, such as carcass ply separations, belt edge separations, tread and sidewall separations, porosity and voids, carcass and belt damage are revealed. All of these defects were recorded on a holographic data sheet.

The data obtained from these data sheets were assembled into a population distribution graph. Using the number of defects found in the initial holograms, Figure 1 shows the population distribution of the defects and the average mileage obtained for each grouping of defects for all the tires that were tested and failed in other than a wearout failure mode. From this graph, predictions of the average mileage obtainable per number of holographic defects may be discerned. It is important to note that there was a problem in assigning a numerical value to the weak, suspicious and degraded areas. Tires with these areas make a significant contribution to the total population. They, in fact, make up nearly one third of the 900 x 20 tires and nearly one half of the 1100 x 20 tires that failed. Thus, it can be seen that the numerical value assigned to these areas will influence the total number of defects assigned to a tire. This in turn will affect the grouping in which the tire will be placed and the average mileage of that grouping.

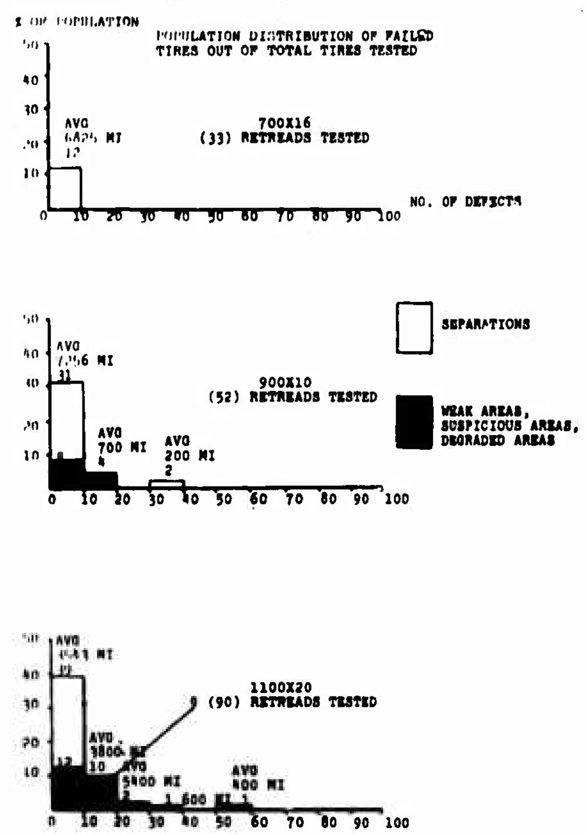

Figure 1

Keeping that in mind, a general trend appears evident from the tires that were tested and failed. The general trend of the greater the number of defects, the greater the probability of tire failure seems to hold true for the 700 x 16's and the 900 x 20's and loosely for the 1100 x 20's.

From all the data studied it seems apparent that the holographic technique of inspecting tires does an excellent job of discovering separations and voids. As far as other defects are concerned, additional refinements in interpretative technique or equipment appear necessary.

When voids or separations are discovered on an initial hologram, there are several possible outcomes. The voids or separations may "grow" and lead to a premature failure or they may remain the same size and have no effect on the life of the tire. This problem of separation growth as tire mileage increases was addressed in our study. It seems apparent from our investigation that not enough is known about this phenomena to determine the mechanisms for separation growth. Some tires that were apparently sound developed rapid separation growth and other tires that were under suspicion had little to no separation growth. Thus, the presence of separation is not always an indication of tire degradation.

Several of the test tires were sectioned to compare actual defects with holographic indications. In all cases, the holographic defects identified as separations were found physically to exist either at the tread rubber-ply cord interface or separation within ply layers. It can then be concluded that where holographic film indicates a separation defect, a separation defect in fact does exist. However, the nature, and criticality of the defect cannot readily be ascertained from the holographic film.

Thus, it seems that *major* separation defects are detectable and can visually be proved to exist. As to these separations, no definitive answer can be given as to their potential to shorten tire life. The weak, suspicious and degraded areas add difficulty to interpreting a hologram which in turn adds to the difficulty in determining their affect on tire life. Finally, a question arises in regards to those tires that are apparently sound with no holographically detectable defects failing prematurely. Part of this could be answered by the fact that the holographic technique cannot detect all defects leaving such defects as ruptured cords and permeable inner liners undetected. Another part of this same problem may be that there are minor defects that are not detectable by holographic techniques, as they now stand, that lead to premature failure.

Thus, it seems that more experience may provide new interpretive techniques to solve some of these problems. As it now stands, much more work is necessary before a commercial version of a holographic inspection system on a production line basis, could become operational.

QUESTIONS AND ANSWERS

Comment: I just want to bring up one point. I think it's kind of important that we had this meeting. There are three people involved in the commercial production unit for ultrasonic testing and none of the systems that are really in this commercial program are represented here. We have Admiral, we have Automation Industries, we have Brannick, all in process on the through-put machine similar to the one at NHTSA which I think is of interest to all of us refitters. I was a little disappointed that somehow or other we didn't get a few minutes to spend on this type of device and talk about the development work.

Mr. Vogel: We thank you for that comment. Mr. Merhib is going to mention the purpose of the working groups a little later on this morning. All I can say as my personal comment to your statement is that Mr. Van Valkenberg has spoken for Automation Industries at the last two meetings and both of the other manufacturers were solicited for papers. Now, I can only go so far, - I can't force them. I can ask them and I can ask you people as the users of this equipment to lean on your suppliers to get papers. I've taken every possible effort I can to roust out papers and the chairmen of your working groups and Mr. Trevisanno as well as Mrs. Earing in the infrared industry have gone out and asked their principals or their contacts in infrared to get out papers. Well we can't. The person they're building it for isn't ready to have it publicized yet, and this is the thing we run into constantly. If Mr. Firestone and Mr. Goodyear have an item under development, he can go to a supplier and say "Okay, you have a release, give a paper but don't squeal about this aspect of it that we don't want publicized." I really don't know how to answer your question except to say that we tried. We went out into all the rubber publications and we went out through ASNT, all of the builders of nondestructive testing equipment and in my capacity in ASNT I know all of them, written to them all personally, and contacted friends. The program you see has all the papers that we were sure were not what you might call crass commercialism. I mean, some people did want to get up and give commercials. We can't have that. We would like to give technical papers, not just a sales pitch. You get that around the trade shows. Go out and try. Give us the papers and if it's not too hard a commercial we'd be delighted to put it in the next program.

MAINTENANCE EXPENDITURE LIMITS BY NDT

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Primarily what I'm going to discuss is the program we have currently for the Army which is called "Maintenance Expenditure Limits of Tires." The basic overall objective of this effort is to develop data and procedures necessary to implement the tire degradation monitoring in the Army system. It is basically: what "accept/reject" levels does one use for each geographic region to obtain the maximum benefits of the system. Split it through several different sections; one will admit that the first area we will encounter were the review of the previous programs we had which led into this. One is what is the effect of water on retreadability - if you use water in the ply sections. The second area of discussion will be the examination of whether entrapped moisture is harmful to tire performance, it's the road test we use down here, and the third area is the result of a survey taken to determine the geographic variability of what we choose to call tire degradation. The last thing I'm going to cover is the simplified example of how you can use this kind of a model, you can save a lot of money when you are managing a lot of tires.

Mainly what we have is a nice collection of cut tire sections for a variety of military tires that are soaking in a fluorescein dye water solution. We took a variety of used tires of the military that had been rejected for various reasons, soaked them from two days to sixty days just to see which ones would absorb water through the cut sections on each one of these tires.

After the sections were done soaking, we proceeded to subdivide the sections into smaller sections and examine each one under lights so that the fluorescent dye would show up in the cords. In a typical cut section, you would see here light areas of the fluorescein dye. If the dye had not penetrated into the cord, the cord structure would be dark, and some of them have cord areas which don't show up because they don't glow with the fluorescent dye.

We did find that a number of tires would absorb water after soaking like this. It turned out from our samples of military tires, almost 100% of the rayon tires would absorb water quite readily, and surprisingly about 10 percent of the nylon tires would absorb water. We at first thought maybe it was the manufacture, a peculiar cord type, or something that was tied with the nylon that could absorb water. We examined that and couldn't find any underlying basis for that. There were different manufacturers, there were different sizes of filaments in the cord bundles - nothing uniform about why they would do it.

We did at this next step look at it and see in terms of retreading application since the worry was if you would absorb water into the plies and the person proceeds to buff the old tread off, rebuild a new tread on and send it out to service, you have some trapped moisture in there, the temperature goes up beyond the boiling point, you're going to turn that trapped water into steam and create separations. The idea was in the case of how does one in terms of retread inspections find out whether the tire actually has water that has been absorbed into it. So we looked around and we found a gadget which is actually used in the wood industry to gage the moisture content in wood at lumber yards to find if it is sufficiently dry to sell to customers so when you build a house your house doesn't need to be crooked, and we found that this actually works quite well. It has a handle with the two needle probes on it and you just insert that into the tire right around the cuts and you can very accurately come out with moisture penetration into the tires from cuts. It's very easy for the liner side so that when the inspector is making his normal liner inspection prior to retreading, he can have a gage like this available, battery powered, the thing is not fairly economical - these gages cost anywhere from $100 to $150 each. You would have to have it calibrated for tires because right now it is calibrated for wood.

The next idea was to find out if there was any way you could predict which tires would absorb moisture. We found that we would cut these tires and we asked ourselves as long as we were doing ultrasonic stuff on the side is there some underlying characteristic in these tires that causes that - the moisture penetration would be detectable by ultrasonics. One of the reasons we felt this way is we sectioned a variety of tires; we looked at them under the microscope; we looked at them under an electron microscope and we find that there are sort of subjective differences between those that would absorb moisture and those that would not. It's obviously not the kind of thing you could use because it's destructive to cut holes in your tires. But we felt that since there were these current structural differences, between the type of tires that would not absorb moisture and tires that had the cords that would, we felt that ultrasonically there

ought to be some way of determining that. So we investigated a variety of those that would absorb moisture that we had found in previous testing and those that would not. We noted some characteristic differences in the signals. We then proceeded to check that by going out to a trailer load of new military tires that we had and picking out the ones that we felt would absorb moisture based on an ultrasonic reading taking them back in, sectioning them, and soaking them. We did find that indeed we could predict those tires ultrasonically which would absorb moisture. That led next to the logical question; are there any mechanical differences between tires that would absorb moisture and those that would not. We then proceeded to start sectioning these tires and doing peel tests and cord-stripping tests on these tires - what we call the hydroscopic tires as opposed to nonhydroscopic tires, and we did indeed find that the hydrosopic tires are weaker than the permitted peel strength levels and are indeed weaker than average population of tires in terms of cord strength. This led us to presume at that point and that they probably would not do quite as well in performing their intended function that is, putting them out on the road and using them as a normal tire. At this point we started going over the tire degradation and doing the road testing and Yuma started monitoring these tires and seeing how these signal characteristics would relate to road testing. And that was described by Leo, Dave, Brian, and Joe earlier so I won't go into that result.

The next step we took in these studies was to go out and actually survey, thinking now in terms of moisture that gets into a tire. I've surveyed a lot of tires at various military installations that they had to see how many injuries cut into the tire, actually had moisture around them. We had one survey done in Arizona, Louisiana, around the Chicago area, out on the east coast, and Virginia. We found that about one to five percent, depending upon which geographic area you were in, of the tires had injuries which had moisture associated with them and we could find moisture penetration into the tire 1/2 inch or greater. Some of the cuts were so large that obviously the tire would be scrapped anyway and would not be retreaded. We did find that anywhere from one to three percent of these tires that had moisture-effected injuries would actually slip through the inspection system according to the Army standard specification for "accept/reject" injury sizes and cut sizes. Which basically says that you are allowing a few tires into the system that do have moisture effected defects, which give you injuries larger than they think you are and actually form the basis for initiation separations. The other bad thing about looking at those tires that do absorb moisture, are also weaker tires to start with, so they are bad candidates to have weakened in the first place.

I just might add here that the engineer taking this test, that ultrasonics doesn't really cause your hair to fall out at this inspection, but we're not so certain the tires might not.

The next part of our effort after we looked at the defects, found that they exist in the real world, with moisture in them, is to take them out on the road and find out how high the temperature can go in a tire that's in actual use. We've seen a lot of people do dynamometer testing to find out how the tire temperatures vary, but we actually wanted to see how they vary on the vehicle in an actual terrain. Basically, we took a jeep tire, instrumented with five thermocouples buried into various portions of the tread. One of them was on the inside liner on the midline, there was a thermocouple on the sidewall, a thermocouple buried halfway down the tread, and thermocouples in the shoulders. We then proceeded to take the jeep out on test runs in the desert. Now the way the transmitting is done, the thermocouples are fed into an FM system and the data is transmitted actually from the rotating wheel into an antenna along the side of the jeep and fed into an FM reader and then comes out digitally, so that we could actually find out what the temperatures were as were traveling real time.

We charted a run of a jeep which basically had two passengers and no other load. The outside temperature at the time of the test was 110 degrees. This was a 50 mhp highway run. The tire I believe was mounted in this case on the front right position. We did try rear wheel positions, left position, to see if there was a diffference from right and left positions from front to rear to see if there was a difference from front to rear in the temperatures generated by the tires and indeed there are differences.

The first run charted is going out along the stretch of road out 40 minutes which is about 30 miles. Then the jeep is stopped, we examine the thermocouples to make sure everything is in place. Then we turned around on the stretch of highway and came back. Interestingly enough here you see that the run out is a little bit cooler than the run coming back. We have theorized that on the run out the wheel was in the shade and on the way back the wheel was in the sunlight. We do find here the thing to look at is primarily along the midline where we had - this tire was selected to be a hydroscopic tire - the tire that we instrumented - we actually injected water into the tire. We then put a thermocouple next to the injected water area, and we wanted to see whether that water area would indeed get up to 212 so we could predict whether the water in there would turn to steam. We did find as we took it out after about 30 minutes into the run, indeed it did hit 212. And we feel like in this case we didn't go up

above it because the water is kind of turning to steam that it absorbed a lot of heat into the system, so it absorbed most of the heat beyond that. But is does say that the moisture-effected defect you can see road operating temperatures that are that high and will turn the water in those defects into steam and can form a potential separation, especially concerning the nature of the tire that tends to absorb moisture.

We then loaded the jeep up with the stated loads that the Army uses out in Yuma. I believe it's 800 pounds they put into the jeep. We took it the same highway run on the jeep and we didn't plot all the data in this particular try, but what I want to show you is the thermocouple that was on the midline that was very close to a liner. The temperature of that climbs slowly up beyond 212, went up to about 240 and suddenly jumped up to 350 or so and then leveled off at about 360 degrees. Away from that area further down into the plies you find that the temperature is steady at about 170 degrees. So our suspicion is what we're seeing is that the scuffing of the inner tube on the tire liner is localized friction and that builds the heat up. We added innertubes in these particular tires so we didn't suffer a tube failure but that's obviously a consideration if you're going to heavy-load vehicles with tire with tubes in them. You can't keep very high temperatures with scuffing action.

In the surveys we're doing, looking for defects, we also wanted to survey those areas to see what the ultrasonic characteristics or the degradation characteristics were of the general population of tires in those areas. We primarily were interested to see how the real world behaves in terms of degradation is compared to the Army tests at Yuma. And so we ran to different geographic regions, we picked different sort of extremes to see this quick and dirty means how tires behave in real life and it's very economical as compared to doing road testing. For hot dry in Arizona, results from populations - these were not Army road test tire populations. In each sort of an ultrasonic category, the category running between 0 and 100, the lower the category the greater the amount of degradation. In this test we saw 55 ran into the very low 0 to 5 category. A new tire, we prefer to see in the 50 percent region so in this case these are actually severely degraded tires so that the use in Arizona is very hard on tires in terms of degradation.

The next test was in cold-moderate climate - the moderate refering to moisture amounts as we were big on moisture at that time. We rated the water availability and the temperature. This cold-moderate test was actually taken in Anchorage, Alaska on tires that are used in Alaskan environment only. You can see that it is not quite as bad as the Yuma results, they're not completely over to 0, but you still find a very heavy preponderence of tires in the lower regions, which says again it's a very harsh environment for a tire in terms of degradation. I am taking you in order from the worst to the least harmful environments. Alaska would be rated as the second most harmful compared to the dry desert which is a very abrasive type.

The next set of statistics are from the hot-wet results which is in Louisiana. There is still a shift to the lower regions of the results considering we've had a hot-wet and a hot-dry does tend to say a lot about the heat which is probably a big factor in causing the degradation. In Alaska it's not clear if its the extreme cold causing the degradation or the very abrasive nature of the terrain. They have gravel roads and that type of thing. But we do again find this skewing over the left of the schedule.

In the Virginia survey, run on a moderate-wet retread area in Virginia, again we found a lot of tires in the lower region. It's not as bad as Louisiana, or as bad as Alaska or Arizona, but it is fairly bad. But one thing that I might mention as we've done this sort of statistic is to find out how many times a retreader is getting a bum rap when he has a lot of problems with his tires. When he keeps getting a lot of tires out in the field his customers come back and say "you guys are doing a rotten job of retreading." We wanted to get a sort of feeling really if it was the retreader causing the problem or are some of these guys were getting very bad casings to work with strength-wise. We do see the differences here so it is quite possible that a retreader can get blamed for things which are truely not under his control. In other words, if he has quite a captive user and the user goes about and uses the things in an environment and a situation that produces a great amount of degradation in the tires in his use. He takes them back to the retreader when the tires start failing on him and says to the retreader "you're the one who's at fault." Well, with this kind of thing the retreader will say "oh no! it's the tires you supplied me with and if you're going to supply me with these kind of casings, you're going to get this type of result." So it has that kind of an importance.

The last case we have is actually a Chicago result, and had a very great amount of difference between them. This is sort of urban driving around Chicago taken in Fort Sheridan, probably on a multi-paved street, probably not too much high speed driving, and no real great temperature extremes. We don't know too much about the nature of the use of the vehicles whether they are heavily loaded or not heavily loaded. But we saw there a completely different background reading than we find anywhere else.

Given the existence of another kind of a curve, we wondered what does that mean in terms of economic benefits for the user. So we started a little bit of playing around using this kind of logic and could obviously see the capability to predict. The capability to predict gives you a great tool to make some very nice economic decisions in managing tires. For example, if I am a retreader and I get a tire in my system that reads in this category down near 0.10, I can say "I don't want to bother retreading that thing because the guy who puts that out in the system again is not likely to go anywhere, it will fail on a 1,000, 2,000, or 3,000 miles and I will have wasted the money I put into retreading, and I will have wasted the guy's effort in mounting and demounting the tire, and I'm also going to have the problem of accident potential and this type of thing." But if I find a tire up in the high region, I'll say "that's great, that's really a nice tire to use again, and that's a tire that will take an economical retread."

To give you an idea of some sort of the logic you can run through, take a 9.00 x 20 tire size, in this case it's a military size tire. The average military cost to retread is say $37.00, the new tire cost is roughly $52.00. We threw in arbitrary factors just for practice. You might complain about these things. You might say that there are $5.00 of these costs involved in transportation, inspection, and paperwork, $15.00 labor in the person's mounting, demounting, inner tubes, valves, etc. The retread cost breakdown is 64 percent for materials, 17 percent for labor, overhead 19 percent; tire loss at the buffer. If you lose a tire at your buffer, if the buffer detects a separation you haven't invested very much in a tire at that point so in materials you haven't lost anything because you haven't put any materials onto it yet, or maybe you've lost a couple of bucks on the handling of the tire up to that point. Overhead at that rate would be $2.30, handling would still be $5.00, you've lost $9.30 on a 9.00 x 20. If you lose the tire on the molder because it's degraded and it blows out at the molder, you've already put your tread on it which you've paid your exise tax on and everything. So you may have lost $24.00 in materials, $5.00 in labor since you've processed it a little bit more, overhead's a little bit higher up to that point, handling is the same, total in that case is $37.50. If it gets through the buffer and the molder but fails in service, you find out you might have the total investment of the $52.00 + $15.00 + $5.00 for handling now that you've invested in the tire. The only way you're going to get that back is to get out the prescribed number of miles out of that tire. In the case of the military they strive for 15,000 miles, so any miles less than 15,000 that it goes is actually going to make that tire more costly to run so we developed a little simple relationship take 15,000 minus the miles driven over 15,000 and it gives you the proportion of the money you're going to get back out of your $72.00, and that will give you a feeling for your losses that you're going to take there.

To carry this thing forward, based on averages, you might lose 3 percent of your tires at the buffer, 3 percent at your molder, these are more of less representative here. You might lose 20 percent in-service carcass failures. Now this is based on road test results that Yuma had - 20 percent of their tires were failing. The average was 7,000 miles rather than the programmed 15,000 miles. You had a few that are due to road hazard failures at 7,000 miles. You have 54 percent that survived to 15,000 miles test. If you assume in the case of the Army that they do 43,500 9.00 x 20 tires annually, you can run through a calculation and see what costs potentially you can save if you can prevent particularly the 3 percent buffer loss and the 3 percent molder loss, which we think we can do. And a lot of the 20 percent in-service carcass, we're going to assume we can prevent 100 percent of it. But whether we can or not we're going to have to find out. If you run through these calculations, you can see you save $12,000 at the buffer station, by keeping the molding losses down you can save $48,000 a year, and by running through the in-service losses you can save $330,000 a year, or a total of $390,000 a year savings by implementing a pre-inspection based on degradation.

For sort of a presentation of logic a person can play with in terms of cost per mile to drive the tire. You get sawtooth type of curves that you can go through as you run a tire out. Actually, the more miles you put on a tire the cheaper it becomes to run. You invest the whole bit in a repair, that raises the cost as you run it out, the costs drop again, maybe you do a repair on it. Otherwise you might compare it say to a radial tire which goes a little bit further before wearing out, it costs more but then you get more miles on it. If you can invest in the cost of a retread, it goes again, you can do cross-comparisons between the tires. Based on this kind of an ultrasonic logic, if you can generate curves like this, which is what we're in the process now of doing for the Army.

So that basically is a summary of some of the things we're doing, and a hodgepodge of some of the things we have done in the past. We talked a little bit about the water type of defect at the last meeting in Atlanta so I kind of slipped through that quickly rather than dragging it out.

Are there any questions?

Q: On the 7x16 jeep that you were running, what was the actual percentage of rated load under the TRA?
A: When they ran them at 800-lb loads, I think its the maximum load, they...Questioner cut in: That was the Army, but compared to the Tire and Rim Association load max what was your load?
A: I can't answer that, maybe 1100 on the vehicle.
Q: On highway at 800 or cross country?
A: We were typically experiencing around 750 lb. per wheel in the front and around 850 (in the rear in Chicago.
Q: The Tire and Rim Association says somewhere around 1700 lb. maximum per tire.
A: That's about right. You can run about 50% total load.
Dr. Ryan, Q: Regarding your cost per mile, is that the cost average for total mileage up to that point or is that a differential cost? It's very confusing, it looks as though you're getting a cheaper cost per mile out of new tires than you ever get out of retreads.
A: Well, you might actually. The costs become what you've invested in the new tire because, say we invest $100 and we drive it one mile before it fails, it costs us $100 a mile to run it. But if I run it 10,000 miles, then the cost to run it is down in the cents per mile category, a penny a mile.
Q: I can't understand that 15,000 miles average wear on a tire. Is that on a real rough surface?
A: The reason we picked 15,000 miles is because that's what the Army specifications says they would like. They purchase tires that supposedly will last 15,000 miles regardless of where they are used, and actually in the tests that were run at Yuma, those tires that did complete the test were capable of going 15,000 miles.
Q: You're talking worn out at 15,000 miles?
A: You have two things working against you, that's a very harsh environment to test tires and I think that the Army pattern which they use is not something that guarantees you a long life. I think your lug pattern is not a long-life tread pattern. They don't have the lug pattern for that reason.
Q: In using your water penetration meter, is that destructive or do you have a way of patching up the holes so you don't get damage.
A: The holes are just pin holes, and we don't find that it's a problem. As a matter of fact, part of our feeling about it is that you won't get minor leaks in good tires anyway, even if you punch holes in them. We were talking to some of the people from Firestone yesterday, and they sort of agree with that. They found that they get lots of things in tires and if the tire is good you can knock holes in it and the plies will not absorb water that easily. But once a tire has reached a worn-out stage, they will. We have seen water go through liners on tires when the liners were totally intact but had very small pinholes. You could smear some kind of a rubber paint over the liner I would expect.
Q: What is the source of the water gage?
A: The name of the thing I was telling you about just escapes me. The company is in New Jersey. It's a wood gage. There used to be one made in Germany but it's no longer made so we had to search for an equivalent. This one is nicer because it has a meter so you can actually make your own rating without being stuck with the manufacturer's. One tire supply has listed a gauge available in their catalog that basically operates the same way for moisture detection but I think that primarily theirs was for surface moisture detection. They wanted to make sure the surface was dry before one put adhesive on it. But they haven't brought any into the country for the past five years. So we shopped for an alternative supplier and that's where we ran across the wood industry's meter.

CHAPTER IV - WORKING GROUP REPORTS

INTRODUCTION

Charles P. Merhib, Moderator
Army Materials and Mechanics Research Center
Watertown, Massachusetts

Mr. Merhib: (Gave concept of Working Groups and their locations, and introduces the chairmen.)
Mr. Merhib: Mr. Bob Yeager of Goodyear has a comment to make on the papers given and also on attempts to get papers.
Mr. Yeager: I would like to commend many of the people who presented papers this morning, but I felt that many of the papers fell short in that I didn't understand exactly what they were trying to get across. You can't separate tire degradation from nondestructive testing, or attempt to define tire degradation without knowing what the stresses are in the tire itself. We have been working on holography for about five years. We have, we feel, the best system in the world to date. We do measure nonuniformities. We have been accurately measuring anomalies and separations for four or five years on thousands of truck, aircraft, and passenger tires. We are working on building some ultrasonic units ourselves, plus many other machines to observe stress patterns in a tire. But coming back to defining degradation, when you talk about degradation you must determine whether it's a bias, belted or a radial, whether it's a steel-belted radial or glass-belted. When you're talking about degradation are you talking about the glass fatigue due to bending, due to compression, or due due to changes in stress, or are you talking about about the centerline of the belt or the edge of the belt, or are you talking about the underlying shear strength between the belt and the carcass, between the wire and the coat-stock - just where are you testing for this so-called degradation? We are working on this tremendously, and welcome an attempt to work with you on a cooperative basis. The atmosphere today is not conducive to giving papers and giving information out or stating facts which can be taken out of context and be used against us. But we'd like to invite you to look at this on a cooperative basis. I believe we do have some knowledge which would be beneficial in getting you pointed in the right direction. There's no reason for you to worry about economics at this point. When you don't have the basic knowledge, you're going to spend the next ten million dollars just getting to what is already available. A few of the many types of degradation can be catastrophic. Some types of degradation in tires we have found do not mean very much. I don't think you can say that any correlation programs that you have presented in the past have worked, or have very much practical value. I haven't yet seen a piece of equipment that's really practical. When you talk 100% inspection of tires or even a quantity approaching that, we think that you must have a much more thorough and broad knowledge of tires in general. We invite the cooperative spirit to be once again adopted between industry and the Government so that we can forge ahead together in these areas rather than duplicating each other's efforts.

X-RAY

Ted G. Neuhaus
Monsanto Industrial Chemicals Company
Akron, Ohio

The X-ray group met for about 1-1/2 hours. I think the reason for this was that X-ray has been established as pretty well developed, there are new items that we'd like to be seen on the systems but I don't think we have too many details to discuss.

I think it was pretty well established that X-ray is here to stay, it's a well established and accepted technique, it's pretty well advanced and as I said, the state-of-the-art is developed. Our major problem in the X-ray area was materials handling, conveying the tire, conversion from the laboratory atmosphere to production. We posed a problem to the audience as to what new items would like to be incorporated in new systems. As usual we had the same comment, the unit price is too high, and, of course, the reason for this is that the volume at this point is not sufficient to decrease the cost of manufacturing. This is a common question; I've heard it for the last three years.

The general opinion was that there is a lack of automatic image analysis. In other words, at this stage the operator is still the grading mechanism; his visual interpretation of the image. In order to increase the volume usage of X-ray systems today, automatic image analysis is required. Also, the discussion of the new fiber B, the Kevlar, the general concensus was that the Kevlar imaging still was not good enough, it could be better; and, of course, faster inspection comes from better resolution to the viewer. There was a suggestion made relative to Kevlar that we add or change the chemistry, add some opaque material to the core to enhance the contrast. Of course, this is a continuing problem that chemists resist in the tire manufacturing process. It was agreed that there was a need for a low cost mobile semi-portable X-ray system to check green tires at the building location. The primary check on this type of machine would be to verify location of belt. It was agreed that the number of cured tires inspected still is in excess of green tire inspection. However, green tire inspection is still important. We asked the question, "will X-ray inspection increase in new tire production?" And, of course, the general answer was only if the original equipment or government dictates this 100 percent inspection. Presently we feel it is a process control check method. Also, we had a question come up as usual, "should we combine X-ray with the uniformity process?" And again the answer to this was that it would be better to separate the two processes.

Belt inspection only is a thing of the past. The machine capability of X-ray system should be able to view bead to bead. We also agreed relative to automatic imagine analysis in replacing the operator that it was possible with the present state-of-the-art to automatically measure spacing and sidewall steel tire construction. This would be done automatically with solid state detectors. In addition to the solid state detectors, you would still be required to view some type of video image. Not putting in a plug for X-ray, but I must admit that most of us are biased. To date, we feel that X-ray is the best overall method of inspection. It's the most comprehensive to the builder, it's the easiest to interpret to the general working man within the tire plant, and we have agreed that probably we have the most installations of this type of inspection today.

It was pointed out in the meeting, six years ago, that X-ray systems were installed quite heavily in the tire plants, and the scrap rate dropped from a 10% figure to 4% with the builders. It was somewhat of a psychological effect and still a very good method in this respect. Also, it was pointed out that new tires today are inspected primarily for constructional control, but also we look for the defects other than the symmetrical uniformity changes. That's the end of my report.

ULTRASONICS

Gwynn K. McConnell
Naval Air Development Center
Warminster, Pennsylvania

Approximately 40 people participated in the Ultrasound working session. I regret that much of the subject matter covered was not introduced during the general paper presentation period. I think there was a lot that might have stimulated further discussion on the floor.

Let me go over major things gone into. It started off with a review of the principles of ultrasonics for tire inspection, and we compared thru-transmission and pulse-echo principles and capabilities, talked about sensitivity, some of the recorded results from the Australian efforts with air-coupled through-transmission ultrasound, Dr. Ryan's experience at DOT, some of my experience with aircraft tires, and General American's with the Army tires. There were a number of questions - unfortunately there were a lot more questions than answers, and we're kind of used to that. There were questions about pattern recognition for degradation measurement. What corrections are necessary with tire construction, type of material, temperature influence, cord size, things along those lines? What calibration standard is realistic for the recognition of degradation? What is the repeatability in the experience that has been gained so far? I think in the limited area of application to date that these questions are quite a problem. General American has made calibration standards using sections of a tire for standards, and they feel that their equipment repeatability is good. Nevertheless, nobody feels they have a good hand on degradation and there is much more needs to be done. The differences between American and Australian emphasis in through-transmission tire inspection equipment use and results were discussed. The Australian people feel that for their aircraft models and for their type of use that they are very successful in operating performance of their retread tires. In this country we do have some added activity but we have not seen any major application or development since the last meeting. We talked about the fact that ultrasonic equipment appears to be highly product or problem oriented and that it may be that many variables will decide a system for a particular problem or product. There was information supplied that a laboratory study by Fabric Research Company in Massachusetts had developed some explanation for fatigue; they had cut tire sections and fatigued them and then studied them microscopically and performed critical tests, and this report is available from Fabric Research Company.

A question came up about what variable in a new tire is indicative of quality. And although there was another similar question that we didn't get around to, general concensus is that there may be some intuition experienced on answers and that we need industry cooperation in getting to the bottom of these questions. We feel that the meeting generated developed additional cooperative effort between the working group participants.

We got a little bit into other applications of NDI two-level products and a little bit of discussion about aging. Unfortunately, we don't have answers to all the questions on the application of ultrasound. However, the application of ultrasonic inspection methods to the quality assurance of tires is starting to demonstrate real capability. During the first symposium, the principles of detecting anomalies with high frequency sound were presented. A second meeting heard discussions along the lines of reduction to practice. This symposium has learned a further reduction of the method to practice with combined efforts of Tank-Automotive Command and General American. We were impressed with the significant instrumentation developments by the Department of Transportation Systems Center and General American. In particular, much interest has been generated by the first presentation of information relating ultrasonic quality measurements to road performance. For safety reasons, and for cost and energy savings, the ability to predict tire performance by degradation classification is most attractive. I took advantage of this opportunity to review current ultrasonic programs and proposed efforts. I am pleased that I have heard so many complimentary remarks about the conference. Some of the people who have real problems with tires are becoming leaders in nondestructive inspection. We are working together, and application studies results have stimulated reaction across the rubber industry and numerous cooperative studies are being formulated.

We found that the critical sounding remarks delivered by one attendee during yesterday's general session were very constructive. However, some Government members and equipment manufactuers feel that they are not receiving sufficient assistance and participation from the tire producing companies. We realize that we are far from answers to questions in many areas. You must appreciate that funding limitations seriously restrict timely progress. A few good people can't resolve everything overnight.

In response to the question, "shall we hold a fourth symposium?" We had unanimous agreement that we should in about 1-1/2 to 2 years. To Paul Vogel, and the hosting activity, Army Materials and Mechanics Research Center, we thank you for another excellent symposium.

INFRARED

Nicholas M. Trivisonno, Senior Research Associate
B.F. Goodrich Company
Brecksville, Ohio

Infrared has not proved to be effective for the nondestructive inspection of tires in the same sense that X-ray, ultrasonics, and holography have been. Infrared does not have the sensitivity of these methods for detecting small flaws in tires. The technique of passing a heat flux through the tire and looking for flaws has been tried. But this method is too slow, and is not sensitive enough to detect small flaws with the low-conductivity materials which make up a tire. Attempts have also been made to heat the tire internally by rolling it on a roadwheel and looking at the temperature pattern generated. This method has not yet proved to be successful for detecting small flaws for short tire heating cycles, but may still be workable eventually.

Infrared does have some unique capabilities which may be useful in detecting tire performance factors which are not detected by other NDI methods. For example, variations in material processing, compounding or cure can cause a tire to run hotter and decrease its durability. This behavior could possibly be detected by infrared in a short, loaded tire rolling test, but could not be detected by other NDI methods. There are commercial infrared instruments for monitoring tires during roadwheel endurance testing to detect the initiation and growth of flaws. This is an NDI test in the sense that the tire does not have to be destroyed to find the flaw, but it does involve testing the tire until some part of it has failed. It is a useful research and development aid. Infrared has also been used as an aid to tire design to determine the effects of material, construction and operating parameters on the operating temperatures, and therefore the durability of tires. Infrared has also been suggested as an on-board detector for underinflated and overheating tires. Infrared instruments are probably too expensive for this use and would present maintenance problems.

In summary, infrared does not appear to have the potential for a fast production line NDI method to detect small flaws in tires in the sense that X-ray and ultrasonics can be used. It does not have the sensitivity for detecting small flaws that holography has. But infrared may have the potential for rapid detection of factors affecting tire operating temperatures that none of these other NDI methods have. The greatest utility of infrared techniques in tire work at present is as a research and development tool to explore the effects of material, construction and operating properties on the running temperatures, durability and power loss of tires, and to detect the generation and growth of flaws in tires being tested. Infrared appears to have limited potential as an on-board sensor to detect potential tire failure.

HOLOGRAPHY

Dr. Ralph M. Grant
Industrial Holographics, Inc.
Auburn Heights, Michigan

Twenty-five people representing twenty companies and government agencies attended the Holography Committee Meeting which lasted over two hours. Each participant presented approximately a five minute summary of his observations on the sessions held over the past two days in addition to providing us with his own particular reflections upon the overall meaning of the importance of the information gathered as it related to the specific needs of his own company or government agency. The participants made numerous comments upon each others opinions.

Our first speaker, Mr. W. C. Shaver of Air Treads provided us with an excellent summary of their holography program over the past four years, in their Atlanta, Georgia plant. They are testing up to 160 tires per day on a production line basis (on Navy high speed tires). He pointed out that, despite many disadvantages, the holography process was indispensable to their operation. He also noted that their tire rejection rate has varied between 0.6 and 13% where tires were rejected if they contained any size separation despite the fact that the Navy requires a 1/2" and larger separation diameter rejection criteria.

Air Treads would like to see cheaper and faster holography machines. Despite the fact that holography sees unbelievably small things, it has not solved all their problems and yet Mr. Shaver says "they can't say enough good things about it." He doesn't think there is any NDT process for aircraft tires which is as accurate as holography.

In a future meeting he would like to see carefully documented papers. In summary, he was quite impressed with the meeting both from an information and attendance point of view.

Mr. C. L. Swinehart of the FAA expressed great appreciation for the privilege of attending the two day sessions. He said that he had learned a lot and that he was quite favorably impressed.

Mr. E. Rueger of Swiss Air in Zurich expressed great interest in our discussions as a newcomer and mentioned that Swiss Air was gathering information to reduce tire failure problems. He found the sessions quite informative. Swiss Air has experienced relatively few failures. Despite this they would like to advance their NDT awareness and capability.

Bill Fiock of General Tire's Corporate quality control group, said he has become more aware of unique apparatus for special problems, however, he would like to see more general purpose equipment for 100% inspection in a factory environment. In summary he has seen many promising ideas and is nonetheless disappointed in not seeing the availability of high speed factory production testing equipment. He felt that the rubber companies should and could be assisting the NDT people with more specific directives, with respect to the industries everyday needs.

Mr. Dave Lindquist of American Airlines, expressed the fact that they have relatively few tire failures but that they really couldn't afford to have any failures, no matter how small the percentage. They need a tool more effective than air needle injection. He has been encouraged by what he has heard and expresses great interest in any and all programs which will help him to provide American with greater protection against loss due to tire failure. He would like to hear more about specific NDT equipment availability.

Mr. Yoneyama of the Bridgestone Tire and Rubber Company of Japan attended our session to see how American companies have been using their holography machines. Bridgestone has been an active user of holography for three or four years.

Mr. Gene Wall of The Goodyear Tire and Rubber Company explained to us that if a rubber company does their early tire development homework on a given tire properly, NDI is not as critical as some might think. When poor attention has been paid to the development of a tire, NDI becomes more critical. One must also be aware of the fact that the airlines must learn to take better care of the tires which they have. He made the point that NDI has become more critical on the newer aircraft particularly aircraft such as the 747 or DC 10 which carry more severe requirements. Load and speed requirements are more severe with each new aircraft. Better NDI is becoming more and more critical, however we should not loose sight of the fact that the early stage tire development work should be carried out with great care.

Mr. Robert Yeager of The Goodyear Tire and Rubber Company explained that holography had several uses at Goodyear both existing and potential.

It could significantly reduce Goodyear tire rejection rates by as much as 50% over the near term (6 months to a year). Even if they spend a half a million dollars for holography he felt that they would experience a definite pay off.

Mr. Yeager says holography is particularly useful to screen test tires such as the ones which are tested on their high speed San Angelo, Texas, test track. They have greatly increased the safety of their testing operations. In tire development which is accompanied by holography a better tire can be produced initially. Individual tire development problems can be more quickly resolved resulting in substantial savings.

In future meetings Mr. Yeager would like to see more on pattern recognition and interpretation of tire defects as a function of individual tire construction details. The basic concept of tire degradation should be more carefully defined and explained. Aside from new tire development he expressed the view that no practical NDI tools are available for the retread job shop. For this purpose ultrasonics rather than holography may have the greatest potential, however, no practical ultrasonics tools are commercially available for retreaders at this time. In ultrasonic test results, he says that one is really never quite sure what they have with respect to a defect despite many test repetitions. When you reject an ultrasonically tested tire you really don't know what you are throwing out. In most cases you really haven't learned anything. You have as great a mystery after you test as before you started. Some better NDI tool needs to be developed for the retread shop.

Mr. Warren Grote and Mr. John Van Hoose of Goodyear Tire expressed particular interest in the new tire development aspects of NDI.

Mr. Ed Pollard of Goodyear Tire provided us with a brief review of holography testing done by Goodyear Tire in Europe and described some real-time holographic experiments which were quite interesting.

He said that real-time holography is not practical for uniformity and strength determination which is necessary for new tire development, but separations can be found. With regard to Goodyear tire holography NDI of radial truck tires in Europe during a three-year period, Goodyear was able to improve their building machines and processes and quality control somewhere between 60 and 70%, which turned out to be of great significance to them. They didn't test 100% of their production volume but they did do a significant volume on a 24-hour basis.

In the future Mr. Pollard would like to see more explanation of holographic tests, namely, interpretation of test results.

Mr. Max Nonnamaker, who is a Product Liability Consultant found the general information to be quite interesting. He provided us with a general review of product liability cases and their relationship to NDI. He provided us with a review of the cost benefits of NDI from a litigation point of view.

Mr. Bruce Richmond of B. F. Goodrich made reference to aircraft tire requirements with respect to larger planes, greater speeds, and loads. He would like to see more participation on the part of the rubber companies. A view which was shared by all committee members.

Mr. Dale Livingstone of Air Treads, formally of Bandag Inc., had hoped to receive more training aids. In view of his direction of ultrasonic and holographic truck tire tests of Bandag Inc. over the past two years he feels that holography is definitely a superior method.

Mr. Kim Butler of Goodyear Tire and Rubber Company would like to see more in-depth technical sessions which would provide us all with a better understanding of our mutual goals.

Mr. Ed Matzkanin from the Yuma Proving Grounds requested opportunities of holography training for his people and we discussed in our group the possibility of putting together a training session.

CHAPTER V - PANEL DISCUSSION

Mr. Merhib: I would like to begin the panel discussion. Are there any questions from the floor?
Ed Matzkanin: It seems like there is one method that has not been represented here: "Has there been any work done in neutron radiography?"
Ted Neuhaus: There's quite a bit of work being done by Harold Burger, who was at one time, as we all know, with Argonne in Chicago. He's now with the Bureau of Standards and he paid a visit to us two or three months ago. As near as I can see, neutrons relate to the chemistry of the rubber itself and very attractively, I would say, as far as air and moisture are concerned. Of course, there is also the safety problem with the neutron as we all realize. I don't know that much about it. I don't think it is an item we would see out on the production line.
Dr. Trevisanno: It's very slow, also, exposure times are quite long. I had a little experience with neutron radiography and as to exposure times you're talking about several hours exposure to get good resolution because of the power required, and the availability of sufficient power.
Ted Neuhaus: I might also say that the state of the art is somewhat reduced because of imaging devices. It's very difficult to image the neutron, as I understand it. The standard imaging devices will not image as well.
Q: Dr. Grant: I would like to know, Paul, if it's in order to bring up a group discussion of the time of the next meeting and the location while we have as many people as are gathered here?
A: Mr. Vogel: To open the discussion I would say that we were fortunate to be able to get into this hotel at this particular time. As was suggested to us in the second symposium we are holding the meeting concurrently with this Akron Rubber Group Winter Meeting. We don't have a feedback yet from Jack Price, the time and place committee chairman. All we can do is get your opinions at Dr. Grant's request. There was talk of various locations, and so just for the record, I will ask for a show of hands on four of the locations that were suggested. We must stay in continental United States, and we must stay within a reasonable distance of a major airline under Department of Army directives that we not spend too much time off the beaten path. An interesting area at this time of the year, for those who are not particularly in love with snow, is New Orleans which has some major facilities in their immediate neighborhood which would be of interest, too. (Nine expressed interest in New Orleans.)

Ed Matzkanin extended the hospitality of Yuma Proving Grounds. Ed is doing some fine work at the Proving Grounds, and even though there is a lot of classified information there, there are areas that may be seen on the grounds. It is the Army's largest installation in the world covering over a million acres of the Yuma Desert. Yuma is located about a half hour by air from Phoenix, and Hughes Air West will lay on a DC-9 for us. There is a shuttle with a regular scheduled airline between Phoenix and Yuma. (Eleven expressed interest in Yuma. A vote of 24 favored Akron on voice from the floor.)
Mr. Merhib: Are there any other questions for the panel?
Dr. Ryan: I don't have a question but I'd like to make a comment that is stimulated by one of the points of interest raised, I believe, by Dr. Grant's presentation that there wasn't a thing that industry would like to see more than a versatile general purpose technique for 100 percent inspection. Our present policy at DOT is really to work toward achieving that, which leads to my personal opinion that pulse-echo ultrasonics has a great deal of potential for that. It is a very versatile technique that can be adapted to most problem areas. I probably didn't emphasize the inspection speed in my talk the other day, but the present DOT machine does the actual scanning and data acquisition in 10 seconds on a tire; that is, from the time the tire actually goes into scanning, and that could be reduced about 3 to 5 seconds so the main limitation is handling as in other techniques.
Q: You mentioned 3600 recaps. Is that all done on one machine?
A: We do not do 3600 recaps a day. I meant that there are about 3600 active retread shops. This could be from a one-man, one-mold operation, on up through a maximum production of any individual shop in the United States which is probably around 1300 or 1400 passenger tires per day. I think the largest truck shop in the States is running somewhere around 350 to 400 units.
Q: On a cost percentage basis on recap, take any given tire, run the life of it, what is the percentage of savings?
Q: Percentage of savings on retread versus new?
Q: Per mile or per landing in an airplane?
A: I'm not really qualified in the aircraft field, but in the commercial retreading field you can figure your average retread cost is going to be somewhere around one-third of a first-line new tire. The cost of a truck tire is much better. A first-line 10.00 x 20 tire is going to cost in excess of $140 to $160, and cost of retreading at the user level is going to be somewhere around $40 to $45.
Q: How does retread mileage compare to new?
A: Actually, most retreads in the commercial field will give approximately equal mileage to new. In the truck market, you can vary. There are some very good compounds out. Bandag, for instance, puts some of the finest materials into their tread stock which I think in some cases

exceeds some of your good new tires, at least on a wear level. The hot-cap retreaders are now putting on materials that are equal to the Bandag, and I believe you can exceed maybe by 10% to 15% of the mileage which was obtained on a good new tire.

Mr. McConnell: Comment: As far as aircraft tires go, we had an experience with one retread use that we kept track of. That was that we had experienced about twice the number of landings with a certain type of retreading, Bandag again, as opposed to the new tire, for a particular aircraft.

Mr. Merhib: I have a comment on the way these sessions have been run. There's no real magic formula as to how you can run several workshops concurrently and yet be everywhere at once. If any of you have any formula that would stagger or set up these workshops so that a person can attend more than one and have himself heard or satisfy whatever problem he may have, we'd appreciate it. I've also been wondering throughout the session here, on the term degradation, is there a universally accepted definition of degradation? Does everyone mean the same thing when they say it?

Comment: Just don't use the word "defect"!

Dr. Ryan: I have an opinion on that, degradation is whatever a degradation meter finds.

Mr. Merhib: If we're not talking the same language, then we've got troubles, or we are measuring different things. I do think that we should start speaking in standard terms.

Mr. Merhib: If we don't have anymore questions, I have just one more for my own interest and that somebody may care to answer: is there an NDT method that appears useful for today and another coming for tomorrow?

Dr. Grant: I think the industry is in much too early a stage to ask these questions of it, and I don't really think these issues are going to be resolved for quite a number of years to come. The answers will be significantly different dependent upon which discipline you are addressing yourself to, whether aircraft tire, truck or passenger, whether original tires or retread tires. The answers are going to be different in different cases. The basic observation that I make, not at the expense of nondestructive testing equipment, is that all of us are looking for a $2.00 solution to a very complicated problem and it is just not in the laws of physics. There are going to be many answers to many situations and those answers are going to be long and slow to come.

Mr. Jannarelli: Comment: I think it is important that the manufacturers of the NDI equipment realize the needs, the peculiar needs, of the retreader, as compared to the new tire industry where the new tire industry can do quite satisfactorily on a sample testing of a small number of samples and achieve a high degree of success in improving their product. The retreaders must inspect every single casing that he is going to retread, and your systems must be fast enough to cope with the volume of some of the larger retreaders. We're talking about many shops in the 350 to 500 or 600 tire per day on less than a 24-hour basis. We're talking in many cases of shops that only run 12 hours, so you're going to have some pretty high throughputs. The retreader is really not expecting you to solve every one of his problems. But you're sure going to give him some help in getting rid of the big loss, I figure around 17 million dollars a year, that is caused just by casing failures.

Q: For Dr. Grant: You used the term "casing uniformity." Is there a correlation between that and tire uniformity which we normally think of as force variation, and if not, is there a means of viewing a tire force variation through holographic technique?

A: Dr. Grant: Yes, there is a correlation between force variation and holographic nonuniformity. They are closely related. We are referring quite often to the overall geometrical uniformity of the tire and then relating, as you would in a stress-strain analysis, the overall response of a ply to stress. Many of the theoretical aspects of this are still very nebulous and are in their very early stages and have not been clearly defined. But we see very close comparison to metallurgical situations, and we do see correlation with force variation, and it bears a strong relationship to geometrical uniformity, the relative placement of the various components in the tire and the response to stress. Or in the sense of relative stress, carefully defined typical stress as the function of the applied load. The thing most significant to us is that in much of the very extensive work done in this area over many millions of miles in truck tire development, there is a very strong correlation statistically, that is, that the uniformity of the stress lines correspond to the performance of the tire in the field. When there is high uniformity there is very high performance, and when there is poor unit structural uniformity from the holographic point of view, there is very poor performance and greatly increased probability of failure in the field. In many cases we wave our hands a lot and say it looks like a Michelin tire and the quality is there and it looks like the fringes have been painted in by Rembrandt, the tire's going to run, run, run, and it will give significantly greater mileage than the tire that looks like it came out of the town dump.

As you go into relative strength, the theoretical considerations comprise an extraordinarily complex field. We on our part are largely tire engineers who are trying to avoid the great cost of allowing rigor to develop into rigor mortis and still keep track of the realities of engineering and physics, as well as the realities of the importance and urgency in doing what we're doing. So much of

it now is the observed data suddenly being reduced in some cases to mileage. But there is a strong correlation between the observed data and the road mileage. Over the last two years there was probably somewhere between 30 to 50 million truck miles; truck tire miles, that have been run under the direct continuous observation of men testing in the field. In the aircraft area we are finding more difficulties with much simulating done; there are a couple of cases with trucks. It is much easier to analyze the truck data than it is the aircraft data, and passenger data is extremely more complex than aircraft data.

Mr. Merhib: I want to thank you very much.

Mr. Vogel: That is the end of the working group session, and if there are no other comments from the floor the meeting is adjourned.

APPENDIX A - BIOGRAPHIES

CHICK, EDWARD E., LTC, is Commander/Deputy Director of the Army Materials and Mechanics Research Center, Watertown, Mass. He has a BS and MS in Metallurgical Engineering from Lehigh University, is a graduate of the US Army Command & General Staff College and various career and specialist courses of the Army Ordnance School and the Army Artillery & Missile School. His 19 years of military experience has been divided between R&D and tactical assignments. He began his active duty at AMMRC in the Metals Research Division; served three years in the Office of the Chief of Research & Development at the Pentagon; and commanded both Artillery and Ordnance units in Vietnam and Korea. He came to AMMRC from duty as the Chief, Materials Branch of the Army's European Research Office, London.

EMERSON, BRIAN, was graduated from Tri-State University in 1971 with a BS in Electrical Engineering. He has been employed at the US Army Tank-Automotive Command since 1972 during which time he received an MA in Management from Webster College. While employed at TACOM, Mr. Emerson has been involved in a wide variety of projects including several which are related to Nondestructive Testing of Tank-Automotive materiel.

GAMACHE, DAVID L., is a graduate of Wayne State University, Detroit, with a BS in Mechanical Engineering. Prior to joining Government service, he worked for nine years for Chrysler Corporation in the development of automotive suspension components. He has been with the Tank-Automotive Command for the past eleven years in the Product Assurance Directorate in the area of quality assurance research. Currently he is Chief, Quality Assurance Division, a part of the new Tank-Automotive Research & Development Command.

GILKEY, JAMES C., received his BS in Mechanical Engineering at Tennessee Technological University, Cookeville, and is currently performing graduate study in Administration of Science and Technology at George Washington University. Since leaving Tennessee, he has been military project engineer at Aberdeen Proving Ground; project engineer in the automotive division of the Office of Research & Engineering of the US Post Office Department; from 1967 to 1971 he served as Supervisory Safety Standards Engineer, Office of Crashworthiness, of the National Highway Traffic Safety Administration (NHTSA), in Washington; and since 1971 he has served as Supervisor, Equipment Group, Office of Standards Enforcement of NHTSA. He is a Registered Professional Engineer.

GRANT, RALPH M., Ph.D., is founder and President of Industrial Holographics, Inc., Auburn Heights, Michigan. He is recognized as a pioneer in the holographic NDT process and the inventor of most applications to NDT of tires by holography. In 1966 he founded GC Optronics, Inc., Ann Arbor, serving as President and Technical Director, and under his guidance GCO became the first independent organization totally engaged in the field of holography (1966-1972). Dr. Grant received his BS in Engineering Mathematics in 1959 at the University of Michigan where he also received his MS degree in Nuclear Engineering in 1961. In 1964 he received his Ph.D. in Physics at the Technical University of the Netherlands, Delft. In 1969, his achievements in conceiving and perfecting applications of holography resulted in his receiving the "Achievement Award" of the American Society for Nondestructive Testing.

HUBINSKY, JOSEPH, was born in Youngstown, Ohio, where he was graduated from the hometown university, Youngstown State, in 1972 with a BE in Mechanical Engineering. He began work with the Government in the same year as an intern in the Quality & Reliability Intern Program. After six months of classroom training at AMETA, Rock Island, Illinois, he was assigned to TACOM, Warren, Michigan, where he completed his intern training. He currently works in the M-113 (Armored Personnel Carrier) Systems Management Office at the Tank-Automotive Research & Development Command.

JOHNSON, RICHARD N., Ph.D., is a Senior Engineer, NDT and Diagnostics Group, GARD, Inc./GATX, Niles, Illinois. He received a BS in Applied Mathematics from the University of Wisconsin-Madison, an MS in Engineering Mechanics from Case-Western Reserve, and a Ph.D. in Engineering Mechanics from the University of Wisconsin-Madison in 1972. He was employed at NASA-Lewis Research Center for six years as a Project Manager in fracture mechanics and materials science research. He has been at GARD for three years involved in materials property research and the development of a numerical street analysis for three-dimensional problems. He was the project manager of the TACOM-sponsored program on tire retreadability and will be the PM on the follow-up research.

KLAASEN, LARRY, was graduated from the University of California, Berkeley, with a BS in Chemistry and he went on to San Diego State University where he obtained his MS in Chemistry. Mr. Klaasen then joined Shell Chemical Company in the field of high polymer aerospace adhesives. He is currently working as a Materials Engineer at the US Naval Air Rework Facility, North Island, San Diego, California. North Island is the cognizant field activity on Navy aircraft tires and is responsible for maintenance engineering and rebuilt tire procurement.

LICHODZIEJEWSKI, W., is Manager, Electronics Systems, of GARD, Inc./GATX in Niles, Illinois, where he has as principal duties the managerial, technical, and sales responsibilities for a group of engineers and scientists working in electronics and diagnostics. He has a BS in Engineering Physics from the University of Illinois in 1963, and an MS in Physics, DePaul University, 1966. In addition to advanced development in NDT technology, his group works in electro-optics, mechanical reliability, and diagnostics, and they provide services on a task basis to generate test specifications and requirements. Earlier, when with Bell & Howell, Mr. Lichodziejewski worked on advanced development of optical systems such as the application of light-emitting diodes to photographic film systems.

McCONNELL, GWYNN K., serves as a Nondestructive Inspection Specialist, Air Vehicle Technology Department, Naval Air Development Center, Warminster, Pennsylvania. He is responsible for the development and application of nondestructive inspection methods for military aircraft. He is a graduate of Temple University with an Associate Degree in Electronics and he has had over 20 years of experience in various areas of research and development. Mr. McConnell is the author of several papers in his field, and the numerous references in the literature to his work in both pulse-echo and through-transmission ultrasonic testing of tires establish him as a highly innovative pioneer in this complex area.

MERHIB, CHARLES P., has served with the Army Materials and Mechanics Research Center for over 16 years, first in ultrasonic research and more recently as Chief, Nondestructive Testing Information Analysis Center Earlier he was with the US Army Natick Laboratories as a physicist in the Physical Testing Laboratory, and prior to that he worked at the development of infrared night vision devices at the Army's Corps of Engineers R&D Laboratories, Ft. Belvoir, Virginia. He is a 1951 graduate of the University of Massachusetts with a BS in Physics and has continued his studies in universities in the Boston area. Mr. Merhib has two patents and numerous publications to his credit, is serving as the Executive Secretary of the Department of Defense Annual Conference on Nondestructive Testing.

MOORE, G. ROBERT, at the time of the symposium was Chairman of the Akron Rubber Group, Inc., having come up through all the usual offices in the Group to that position of leadership. He started in the rubber industry 26 years ago as a research chemist, went on into technical service work, and then into technical sales with B. F. Goodrich. He joined Harwick Chemical in 1960 to open their Oakland, California office, then returned to Akron in 1965 as District Manager and moved up to Vice President in 1968. Mr. Moore is a native of Akron, a graduate of Kent State, and a leader in many civic activities involving youth sports and scouting.

NEUHAUS, TED G., at the time of the symposium was Tire Systems Manager for Picker Corporation, Cleveland, Ohio. He has been in the field of industrial and tire X-ray since his graduation from Ohio University, Athens, Ohio, BS, 1956. Mr. Neuhaus has been an active member of ASNT, ASTM, ACS, and ASQC, has chaired many committees, and has presented papers to local and national meetings and educational groups. One of his recent contributions to the rubber industry is a patent for the air-inflated, bead-to-bead inspection, X-ray production system. Subsequent to the symposium, in March 1977, in a merger, he was placed in charge of Sales of Tire Inspection Systems at Monsanto Company, Akron, Ohio.

RYAN, ROBERT PATRICK, Ph.D., received his MS in 1959, and Ph.D. in Physics in 1963 at Brown University, Providence, Rhode Island. His academic and professional background and honors are too extensive to summarize, but some of his achievements include acoustic noise measurements and time-frequency analysis related to acoustic minesweeping, use of seismic techniques for determining sea-bottom structure, study of leaky waveguide effects in underwater sound propagation, radiation field patterns, instrumentation for measurement of degradation of the pulse width of sub-nanosecond laser pulses, studies of optical modulation and detection techniques for high data rate laser communication systems, and others. Dr. Ryan has been with the Transportation Systems Center, Cambridge, Massachusetts, since its conversion from the NASA-Electronics Research Center, where he served as a physicist.

RYDER, JOHN C., is Vice President of Engineering and Manufacturing for Fabricated Machine Company of Massillon, Ohio. He has many years of experience in tire test machinery design as well as tire design, and for seven years he was with Firestone Tire Test Development and Advanced Tire Development. At Fabricated Machine Company, he has managed the tire testing subsidiary, Standards Testing Laboratories, and has been responsible for its manufacturing and engineering functions for the past three years. He holds a MSME degree from Rensselaer Polytechnic Institute and is a Registered Professional Engineer in the state of Ohio.

SCHURING, DIETERICH J., Ph.D., at the time of the symposium was Principal Research Engineer, Vehicle Research Department, Calspan, Corp., where he has been employed since 1968. Prior to that position he was with AC-Electronics Defense Research Laboratories for 5 years, with Battelle Institute, Germany, for four years, and with Organic Terrain Research Institute, Germany,

1952-1959. Dr. Schuring's most recent work concentrated on theoretical and experimental aspects of tires, with particular attention given to wear and traction, mathematical modeling of tire performance, and thermal tire characteristics. His earlier work included analysis of dynamics of lunar vehicles, development of wheels and tracks for cross-country vehicles, and investigations of rheological properties of soil. He is a founder-member of The International Society for Terrain-Vehicle Systems. He is now with Firestone Research Division, Akron, Ohio.

VOGEL, PAUL E. J., a Registered Professional Engineer, serves as a Research Mechanical Engineer at the Army Materials and Mechanics Research Center where he joined the NDT function after graduating from the US Army Command & General Staff College, Fort Leavenworth. He has authored over 30 papers in infrared applications ranging from tire testing to energy conservation and has also published in ultrasonics and acoustical holography. He is active in SPIE, IRIS, the NDT Forum of the Air Transport Association and he holds a number of positions in ASNT including the chair of the Committee on Infrared Techniques for Materials Evaluation, and the ASNT Handbook Coordinator for Infrared & Thermal Testing.

WALKER, RICHARD S., was born in Massachusetts and attended school there before going on to Lehigh University where he earned his BS in Chemical Engineering in 1950. He entered the rubber industry as a chemist with the H.O. Canfield Co. in Bridgeport, Connecticut, and was later transferred to the company's new facility at Clifton Forge, Virginia, as Chief Chemist. Other positions in industry include sales engineer with the Goodyear Chemical Division, supervisor in the development and technical service department of Thiokol Chemical Company, and advertising and promotion manager for the R.T. Vanderbilt Company. Mr. Walker joined RUBBER WORLD first as technical editor and has had increasing responsibilities during his ten-year literary career. Mr. Walker has since joined Rubber & Plastics News as Executive Editor.

WEIR, JAMES D., and WEIR, KAY, the co-authors of the paper herein, have been together as a team in life and in the rubber industry for over 30 years. Jim was operator of a retread plant for ten years, was Director of Testing for International Rubber Industries in Louisville where he developed the glass fiber-belted tire for Owens Corning, and he was President of Retread Technical Corp., Los Angeles, until 1973 when he retired to consult to retreaders and manufacturers and to work more closely with Kay and their son in designing and building machinery for the rubber industry. Mrs. Weir owns and operates the TIRE PRESS, writing and publishing tire articles and books.

APPENDIX B - ATTENDANCE ROSTER

NONDESTRUCTIVE TIRE TESTING SYMPOSIUM

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
SUPPORTED BY THE
AMERICAN ORDNANCE ASSOCIATION

27-29 January 1976

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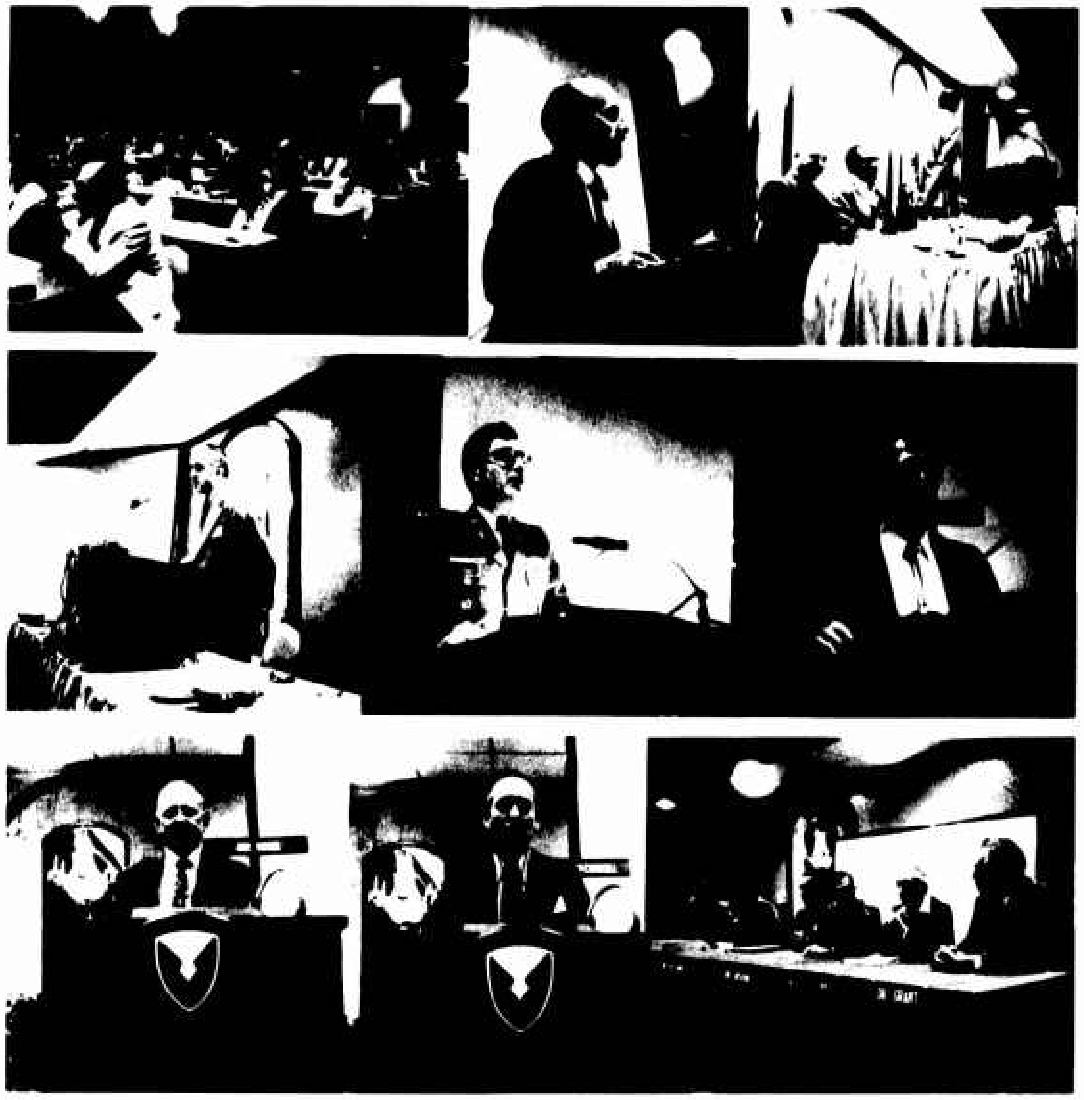
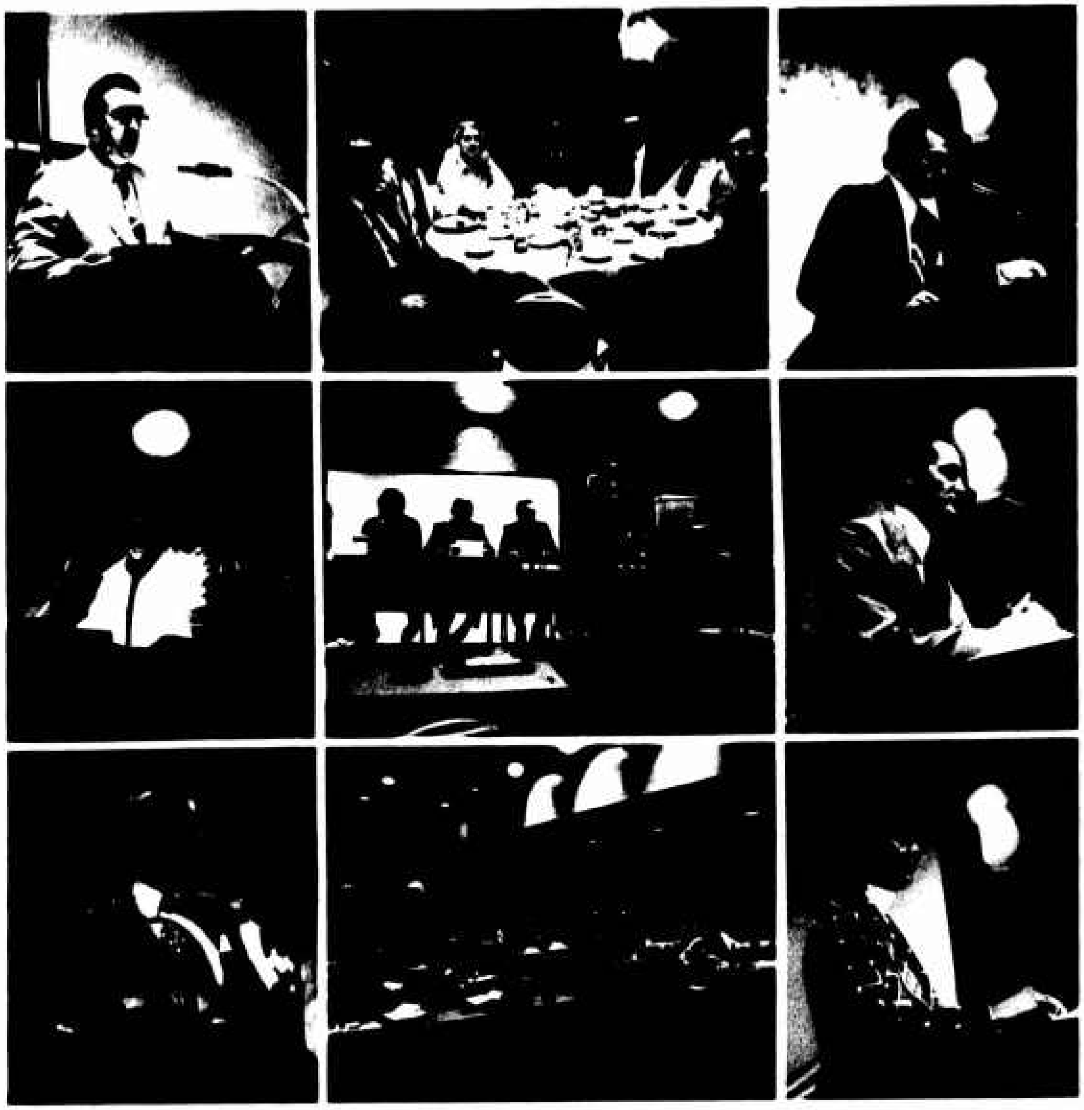
CONFERENCE SCENES

(Left to right) (top row) Mr. Walker; banquet scene; Dr. Johnson; (middle row) Mr. Emerson; Welcome to Akron; Mr. Gamache; (bottom row) Mr. Hubinsky; Aircraft Tire Committee Meeting; Dr. Grant.



(Left to right) (top row) Meeting scene; Dr. Ryan; Banquet scene with Mr. Jannarelli and Mr. Lewis; (middle row) Mr. Gilkey; LTC Chick; Mr. Merhib; (bottom row) Mr. Vogel; Mr. McConnell; the Working Group panel.

(Left to right) (top row) Banquet scene; Mr. Gilkey and LTC Chick; Panel members; (middle row) Mr. Jannarelli and Mr. Gilkey; Cathy O'Keefe and Mary Ann Beradi from AMMRC; Panel members; (bottom row) Panel members; view to the platform; some of the European visitors, Mr. Rueger of Swissair, Mr. Vogel, Mr. Geissler of Lufthansa, and Mr. Kruger of Continental Gummi-Werke.



(Left to right) (top row) Mr. Moore; attendees from AMMRC at banquet; Mr. Lichodziejewski; (middle row) Mr. Weir; Working Group Panel; Mr. Ryder; (bottom row) Dr. Schuring; a meeting scene; Mr. Klaasen.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978 702-870

AMMRC SP 80-1

PROCEEDINGS OF THE FOURTH SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

Sponsored by
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

PROCEEDINGS OF THE FOURTH SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

Dedicated to

Paul E. J. Vogel

Mechanics and Engineering Laboratory
Army Materials and Mechanics Research Center

23-25 May 1978

The Executive Hotel, Buffalo, N. Y.

Sponsored by

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

Approved for public release; distribution unlimited.

This document was published by
the Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEDICATION

This proceedings, the last in a series of four, is dedicated to Paul E. J. Vogel, Chairman of all four symposia, who retired from the Army Materials and Mechanics Research Center in January 1979. Paul was the originator of these symposia which were successful mainly due to his untiring efforts in their behalf.

We at AMMRC wish Paul all happiness on his ranch in Florida, and wish him success in his future business endeavors.

PREFACE

This symposium was designed for the exchange of nondestructive tire testing technology. It was especially aimed at the identification of needs and opportunities in the field and the development of recommendations for the DoD Tire Testing Technology programs and to some extent the needs were identified. Possibly the foremost of these is the need to perform a thorough survey of the state-of-the-art so that DoD testing technology programs can best be related to existing techniques or to practical techniques that need further development. It is hoped that the dialogue that was enjoyed throughout the four symposia will continue by correspondence and visits by all interested elements of the field.

A symposium such as this one could not have been successfully held without the cooperative hard work of a number of people. Thanks are due to many: To Paul Vogel and his committee: D. Gamache, TARADCOM, G. McConnell, NADC, R. Yeager, Goodyear Tire, Jack Price, Air Treads, and C. Merhib, AMMRC; to Kathy Seege of the Executive Hotel for her fine personal efforts expended to assure arrangements were the best available; to personnel of Calspan for the tour provided; to F. James Henry, Buffalo District, U. S. Army Corps of Engineers, for the fascinating dinner talk on the "Dewatering of the American Falls" which gave added interest to the town of Niagara Falls following the Symposium, and to Jim Larson representing the Mayor of Buffalo for providing the welcome.

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23 May 1978

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0905 Hours	WELCOME TO BUFFALO James H. Larsen, The Charter House Motel
0910 Hours	OPENING REMARKS Col. W. R. Benoit, U.S.A., Commander, Army Materials and Mechanics Research Center
0925 Hours	KEYNOTE ADDRESS A. L. Lavery, Transportation Systems Center
0955 Hours	INTRODUCTION OF WORKING GROUP CHAIRMAN Paul E. J. Vogel, Army Materials and Mechanics Research Center
1020 Hours	BREAK
1040 Hours	AIRCRAFT TIRE MECHANICAL PROPERTY TESTING J. R. Hampton, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio
1110 Hours	SIZE CRITICALITY STUDY IN NAVY AIRCRAFT TIRES L. Klaasen and M. Fontanoz, Naval Air Rework Facility, North Island, California
1140 Hours	IMPROVING QUALITY AND EFFICIENCY OF MILITARY TIRES FOR LOW LIFE CYCLE COSTING S. Kyriakides, Chem-Pro Manufacturing Company, Buffalo, New York
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1330 Hours	BEAD INSPECTION TECHNIQUES BY BENDING RIGIDITY AND CONTOUR MEASUREMENTS S. K. Clark, R. N. Dodge, and R. M. Larson, The University of Michigan, College of Engineering, Ann Arbor, Michigan
1400 Hours	A NEW APPROACH TO NONDESTRUCTIVE ENDURANCE TESTING OF TIRES A. Stiebel, Uniroyal Tire Company, Detroit, Michigan
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1530 Hours	AUTOMATIC ANALYSIS OF HOLOGRAPHIC INTERFEROGRAMS R. E. Haskell, Industrial Holographics, Inc., Auburn Heights, Michigan
1600 Hours	COMMENTS UPON THE PAST, PRESENT, AND FUTURE OF HOLOGRAPHIC NDT OF PNEUMATIC TIRES T. R. Zimmerman, Industrial Holographics, Inc., Auburn Heights, Michigan

1630 Hours	FAILURE ANALYSIS OF AIRCRAFT TIRES AS OBSERVED BY HOLOGRAPHY R. M. Grant, Industrial Holographics, Inc., Auburn Heights, Michigan
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	BANQUET SPEAKER Mr. F. James Henry, Buffalo District, U. S. Army Corps of Engineers, "The Dewatering of the American Falls," The story of 1969 shut-off of the Niagara River to the American Falls.
24 May 1978	
0830 Hours	EXPERIENCE OF TIRE DEGRADATION MONITOR IN COMMERCIAL APPLICATIONS R. Johnson, GARD/GATX, Niles, Illinois
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0930 Hours	A SECOND GENERATION HOLOGRAPHIC TIRE TESTING UNIT H. Rottenkolber, Rottenkolber Holo System GMBH, D8201 Obing-Allertsham 4, West Germany
1020 Hours	BREAK
1040 Hours	PRODUCTION X-RAY, 1978 T. Neuhaus, Monsanto Company, Akron, Ohio
1110 Hours	SOME NEW TRENDS AND DIRECTIONS IN THE WORLD OF SPECIFICATIONS AND STANDARDS R. Chait, Army Materials and Mechanics Research Center, Watertown, Massachusetts
1130 Hours	DISCUSSION OF THE NEED FOR SOME STANDARDIZATION IN THE FIELD OF NDT OF TIRES R. Yeager, Chairman of the Ad Hoc Committee on Standards
1200 Hours	LUNCHEON
1330 Hours	ULTRASONIC TIRE INSPECTION R. Watts, Product Assurance Directorate, U. S. Army Tank-Automotive Research and Development Command, Warren, Michigan
1400 Hours	TIRE SEALANTS, FUNCTIONAL REQUIREMENTS; STATE OF THE ART; PROBLEM AREAS; ECONOMICS L. Bruce Ritchie, Ti'Seco, Ltd., London, Ontario
1500 Hours	WORKING GROUP MEETINGS Chairman, C. Merhib ULTRASOUND — I. Kraska HOLOGRAPHY — R. Grant STANDARDS — R. Yeager QUALIFICATION — G. McConnell X-RAY — D. Greene
25 May 1978	
0900 Hours	CONVENE MEETING Charles P. Merhib, Moderator
0905 Hours	WORKING GROUP REPORTS Each working group will present a summary of its findings and recommendations.
1030 Hours	PANEL DISCUSSION
1200 Hours	ADJOURN

CHAPTER I

OPENING REMARKS

COL William R. Benoit
Commander, Army Materials and Mechanics
Research Center, Watertown, Mass.

Thank you Mr. Vogel, our Chairman; Mr. Lavery; and attendees of the Fourth Symposium on Nondestructive Testing of Tires. It's a pleasure indeed for me to be here in Buffalo and have an opportunity to give this address.

The Chairman has told you about my military background. I have always been associated with either aircraft or rubber-tire vehicles, with the exception of one organization where I had the only train in the United States Army. In the last command tour that I had, which was a maintenance battalion, we had two transportation truck companies so I know a little bit about the problems with tires; especially retread tires. And as a rated pilot I've flown aircraft with tires that were recapped with 100,000 miles of life not being unusual at all. Of course the rubber was off the ground for most of those miles. Now some of our tires are not really the sort that you would necessarily prefer to trust your life to because you always find that out after the fact. Under Army Regulation 750-36, which is in force now, we are mandated in the army to use 75% of our tires as retreads, 75% of the tires that we get now are retreads. Mr. Vogel, your Chairman, happens to be very prominent in the Reserve and National Guard back in his home state of Massachusetts and he probably wouldn't care to name the unit, but he knows of one unit where they put the retreaded tires on, drive around the motor pool, and then they take them off and then put new tires on because they don't trust retreads. Some of the units put the retreads on the rear wheels only because they don't want to put the danger of having the front tires blow out. As you know, our jeeps now have four wheel independent suspension and a rear wheel blow out can be disasterous as well, so I don't know what they do in that case. I don't want to sound like the preacher who chews out the attendees on the evils of non-attendance but I do want to point out one of the more serious problem areas and you who are here are interested in the latest developments in nondestructive testing for assurance of top quality tires. So you are what we would call the good guys, the white hats, and as we know the good guys are imposed upon by everyone and so I'm not going to be an exception I'm going to place an imposition on you here today. I'm here to say that the army needs help and that's the basic purpose of this Symposium. We want you to tell us which of the hundreds of possible irregularities in a tire can be considered to be serious enough to warrant rejection. We want to know which of the serious irregularities can be identified by nondestructive testing techniques. We want to know what hope there is of developing tests that will be meaningful or lowering the costs of tests that are in use: because it's obvious we have a cost problem, otherwise we probably would not take advantage of retreads. We must establish Army goals and then concentrate our efforts on attaining these goals. Now I don't pretend to be a tire expert; I'm just a user of tires, but I do know that you have the combined expertise here in this room to point us in the right direction. Keep one thing in mind throughout your deliberations; we really need your help. We don't have the answer. For that reason we are asking you to assist in forming recommendations and comments on identifying the priority needs in the tire test area and we'll do this through the medium of the working groups, as you know, and a panel discussion that Mr. Merhib will tell you about. A working group chairman will try to package your thoughts at the end of this and express your best thoughts about this. Now one important phase of the working group activities will be the problem area that's been common to all of us and that's the need for a common language in discussing nondestructive testing of tires. Mr. Bob Yeager will chair this particular working group and many of you will remember him from Akron where he expressed concern for a common nomenclature for tire nondestructive testing. I wish to thank Goodyear Tire and Rubber for allowing Mr. Yeager to work with us this year in probing the questions of the need of some standardization of tire testing nomenclature, equipment performance, etc. It's a sensitive question but it is in the hands of a man who has an unusually broad knowledge of tires and suspension problems and who will have in mind the best interest of the entire rubber industry as he leads his group work.

Now back in New England, we have a form of Government known as the Town Meeting in most communities, certainly the one that I grew up in. This allows every citizen to stand up and be heard if he wishes. I'd like to tell a little

story. In one of the meetings, a man stood up and said, "I understand that when little Suzie Jones had her baby the town paid $125 for the delivery." The moderator answered as to how that was correct. And the man continued and said, "and I understand the State reimbursed the town $150 for that delivery." And the moderator agreed that that was the right figure. "Well then," said the speaker, "since this is the first transaction in which the town has shown a profit, I make a motion we breed her again."

We were going to stop these tire symposia after three meetings but they've been so mutually profitable that we've decided to breed her again. That's why we're here today. Between us, I'm sure we can show a profit for the Army and the manufacturers of tires and tire test equipment, and also for the taxpayer who pays for our research and buys tires and retreads.

I look forward with interest to your panel formulation of identifying needs and solutions for DoD tire testing improvement. Thank you very much.

CHAPTER II

KEYNOTE ADDRESS

A. L. Lavery
Transportation Systems Center
Cambridge, Massachusetts

It is an honor to be the keynote speaker for the Fourth Symposium on Nondestructive Testing of Tires. This meeting is sponsored by the Army Materials and Mechanics Research Center which is located in Watertown, Mass. The purpose of the meeting is to foster the exchange of nondestructive tire testing technology, to identify needs and opportunities within the field, and to develop recommendations for the DOD tire testing technology program. This program is concerned with new tires, stored tire degradation, and retreaded tires for use on operational ground vehicles, support equipment, and aircraft. Current military regulations call for the utilization of retreaded tires for many of this equipment. The Army Regulations call for a 75% use of retreaded tires. It is in this area that a considerable amount of the current work is centered.

In the first of this series of symposia, Richard D. Meyer, Assistant to the President, Firestone Tire and Rubber Co., was the industrial keynoter. In his address, he characterized the nature of tires and the desirable features of an NDT system to inspect tires. Since I believe that his remarks are still meaningful, I will take the liberty of paraphrasing them. On the characterization of tires, the following were the principal parts.

- A tire designer has approximately 20,000 theoretical options for tire design.
- A tire is an individual assembly of components. When it fails, it must generally be totally replaced.
- Variations in the components and the artisan tire builder produces a product which will differ from the norm. Sampling does not give absolute assurance that each tire in a batch behaves like the sample.
- Use factors, including the operator, affects tire performance by widely measurable degrees.

These brief summary comments imply that this composite we call tires are indeed a complex system. It is this very factor which makes this field of the nondestructive testing of tires so difficult and so challenging.

The principal points he made for an inspection systems' characteristics follows:

- Perceived benefits must be equal to or greater than the cost of inspection.
- The method must be production oriented to inspect 100% of the product.
- It cannot be too delicate and must be easily maintained.
- It must be consistent and produce identical values of identical items and provide these results in an easily interpreted manner.
- It must measure parameters which are verifiable through road or other physical testing.

I believe the above remarks were particularly meaningful since they represented the view of a senior tire company executive concerning a complex engineering problem.

During the course of this symposium, we will hear about the current progress in many areas, including tire mechanics, critical defect size, and nondestructive testing of beads and carcasses by ultrasonic, holographic, x-ray, and other methods. Clearly, many of the methods which will be reported upon will generally meet the previously stated characteristics for a tire inspection system. As engineers, we will recognize the innovative approaches and the engineering difficulties. We will also relate our experience to those reported upon and leave this symposium with a broader knowledge and better understanding of this tire inspection area. But this better technical understanding will not guarantee the success of either the industry or government tire inspection programs. Since very few of us here are the policy makers who approve major buys for this type of equipment, it might be beneficial to look at a few of the factors which are required to make such buys possible.

First, there must be a *need*. The need may be based upon a decision such as decreasing tire adjustments, complying with a 75% retread regulation, screening compliance test tires, or the evaluation of physical testing. As a result of these types of decisions, a need to provide inspection methods (which could be either visual or instrumentation) can be identified. The identification of the specific need bounds the problem. It allows the specific identification

of potential benefits. The benefits can, of course, take many forms. They may relate to the readiness of combat units, the safety of aircraft, or the reduction of tire adjustments. One often includes the cost of litigation, and societal costs as part of the estimation of benefits. Policy decisions are often based in part upon the ratio between the *benefits* and the *cost* of implementing the inspection process to fulfill the need.

Since most solutions to a specific need are not 100% effective, the potential benefits are adjusted to determine effective benefits. This approach provides the general basis for the benefit/cost and return on investment considerations which so many policy decisions consider. From the engineering viewpoint, the cost of implementing a method for inspection and its effectiveness in fulfilling a specific need can be seen to have a definite impact on the decision to deploy a candidate inspection system.

The second problem is to determine which *physical parameters* must be controlled to meet the specific need. Stated another way, what are the failure modes and the precursors of failure, which if they are eliminated, would satisfy the need. This part of the process is perhaps the most difficult and yet the most neglected part of many inspection programs. Those of you who have inspected tires for separations, found them, and then not having them propogate to failure during wheel or road tests, while a separation-free tire failed the same test due to separations, will appreciate the problem. Could it be that in *new* tires the presence of small separations is not necessarily indicative of either poor quality control or potential product failure? If this is so, then perhaps the precursor to tire failure due to the separation mode may be either in the components, the adhesion between components or in allowable design variations. These factors *must* be determined before the design of inspection methods to control this failure mode can be developed. Most of the needs which are addressed by the various tire inspections programs are concerned with several potential tire failure modes. Thus, the requirement exists to identify each failure mode, the probability of failure for each failure mode, and the mechanics of the failure mechanisms. This approach will provide information necessary to properly apportion program resources, and to identify the potential measurables at the point of inspection for controlling the failure mode. It is very important to identify these measurables or latent defects related to the mechanics of failure which would exist at the point of inspection. For example, if one can only identify a latent defect after 1,000 miles of road use, then an inspection system for use at the manufacturing point to control that failure mode would have no utility. In fact, work to develop such a device by consuming valuable resources with a nil probability of controlling the failure mode would have a very negative impact on the overall success of a program.

The third step in a successful inspection program is the development of suitable *inspection methods*. In this development, the inspection methods must fulfill the requirements as to cost, the detection of those precursors of failure, time of inspection, maintainability, and operation within the physical environment. The cost elements include capital equipment, operators, maintenance, consumable supplies, spaces occupied, and the percentage of product rejected due to false alarms. There is, of course, a relationship between the detection probability and the false alarm rate. Generally, the more subtle the precursor to the failure mode being detected the greater the false alarm rate. The trade-off is always to a lower detection probability to obtain an acceptable false alarm rate. Inspection cost is also directly impacted by the inspection time. The greater the time the greater the cost. The trade-offs between the cost elements and the ability of an NDT system to satisfactorily meet the other requirements represents a difficult engineering challenge. However, this challenge must be met to provide an inspection system capable of successfully meeting the criteria for a stated benefit/cost ratio or a required return on investment. If the criteria cannot be met, then the method is unlikely to be deployed.

During the course of this conference and its workshops, we each have an opportunity to impact the outcome of the several tire inspection programs sponsored by industry and government groups. This positive impact can be in the following area:

- the definition of needs and benefits
- the identification of failure modes, probability of failure for each mode, and the failure mechanics leading to each failure mode
- to continue to develop cost effective inspection system
- and to characterize these systems as to the probability of detection and false alarm rate.

As you know, these are difficult challenges. You, the collective attendees at this meeting represent the principal expertise in tire mechanics and tire inspection technology within this country. I am confident that you will meet this challenge and make the nondestructive testing of tires even more successful in the future than you have in the past. Good luck and thank you!

CHAPTER III

AIRCRAFT TIRE MECHANICAL PROPERTY TESTING

James R. Hampton
Air Force Flight Dynamics Laboratory
Wright-Patterson Air Force Base, Ohio

Tire mechanical properties are forces, moments, and other load reactions exhibited by tires when in contact with a surface. These properties must be measured and specified for aircraft tires in order that landing gear designers and engineers can properly integrate their influence into overall aircraft ground performance and handling. They are also necessary for improving tire manufacturing techniques, processes and materials for optimization of the ground performance of an aircraft tire while maintaining or improving other aspects of tire performance such as wear and cut resistance. The trend of high performance aircraft is toward higher take off speeds with the tires being required to fit in smaller envelopes and be inflated to higher pressures. This trend has contributed toward the problems of aircraft directional control during take off and landing and in a number of incidents involving "veer off" and "runway overshoot", particularly during landing on wet or icy runways and during crosswind situations.

In contrast to automotive tires, the mechanical properties of aircraft tires are largely unknown. This lack of data is a significant deficiency in landing gear design and in the prevention of, or solution to, landing gear problems involving shimmy, steering, traction, and cornering. Tire performance characteristics have an effect upon and interact with the strut, brakes, antiskid and steering systems. To understand these interactions and their effect on the landing gear system, a complete set of aircraft tire mechanical property data must be available.

Unique tire test capabilities exist at the Air Force Flight Dynamics Laboratory (AFFDL) which allows for the accurate measurement of aircraft tire mechanical properties. These properties are compiled with the use of a flat surface tire force machine and a computer controlled, 120 inch dynamometer test system. Both of these test systems support a tire/wheel assembly by a metrical frame containing six load cells through which the loads are applied and the resultant tire forces and moments are reacted.

The data obtained from these test machines provide basic information on how well aircraft tires can be expected to perform their function. The data can also be used to aid landing gear and tire engineers and designers in dealing with tire related problems such as shimmy, wear, ground handling, steering, brake, antiskid performance and vertical energy absorption.

An aircraft tire must support the weight of an aircraft and its contact with the pavement must generate all ground control forces during taxi, take off, and landing. These forces include the fore and aft frictional resistance during braking and the lateral forces necessary for directional control in crosswind operations and in turning. The tire must absorb impact landings, and together with the shock strut dissipate the vertical kinetic energy of the aircraft during landing. The tire must also demonstrate adequate structural fatigue life and long tread life.

The aircraft tire plays a dominant role in the overall performance of the landing gear. The tire mechanical properties have an effect upon and interact with the strut, brakes, antiskid and steering. Tire mechanical properties are known to be primary contributors to "gear walk", shimmy, and truck "pitching", which are various forms of dynamic instability. Other types of interactions also occur; for example, brake application reduces the ability of the tire to provide lateral steering force. This, in turn, can lead to a loss of directional control of the aircraft, particularly on wet runways.

Developing and fabricating aircraft tires can best be categorized as an art rather than a science. Aircraft tire development is accomplished largely by "build and try" methods. Design and manufacture, particularly the rubber compounds used, are highly proprietary to the individual manufacturers. The missing link is the technical capability of measuring, correlating, and specifying the performance characteristics of tires, in addition to structural integrity and wear. The AFFDL flat surface tire force machine and the 120 inch programmable dynamometer provide the means to fill this technology gap.

FLAT SURFACE TIRE FORCE MACHINE

The AFFDL/FEM flat surface tire force machine is the first indoor laboratory machine designed for the measurement of aircraft tire properties under aircraft loads with combined steering, camber and braking on flat pavements (see Fig. 1). It accommodates tires in a size range between 16 inches and 56 inches outside diameter, with vertical loadings up to 80,000 lbs., and is instrumented to measure all six force and moment components developed by the tires. The machine is designed to permit low speed tests at slip (yaw) angles between ± 90 degrees

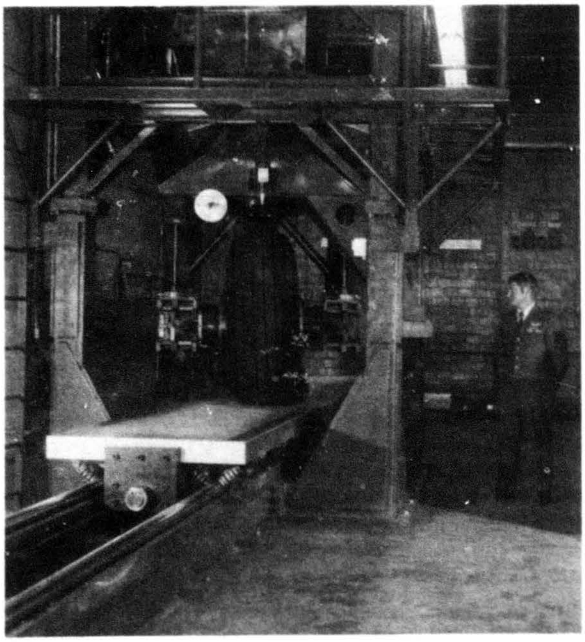


FIGURE 1
FLAT SURFACE TIRE FORCE MACHINE

the ±90 degree position is used for lateral stiffness tests), camber angles between ±20 degrees, and any desired value of longitudinal slip. The force measuring system consists of a series of six Model 1220 Interface Load Cells. Automatic data logging on analog magnetic tape recording equipment provide for accurate recording of data for rapid processing. The data acquisition and data processing flow chart is shown in Fig. 2. The moveable table is constructed such that the normal test surface may be replaced with slabs of various paving materials such as concrete and asphalt. In addition, soil trays may be added for flotation studies.

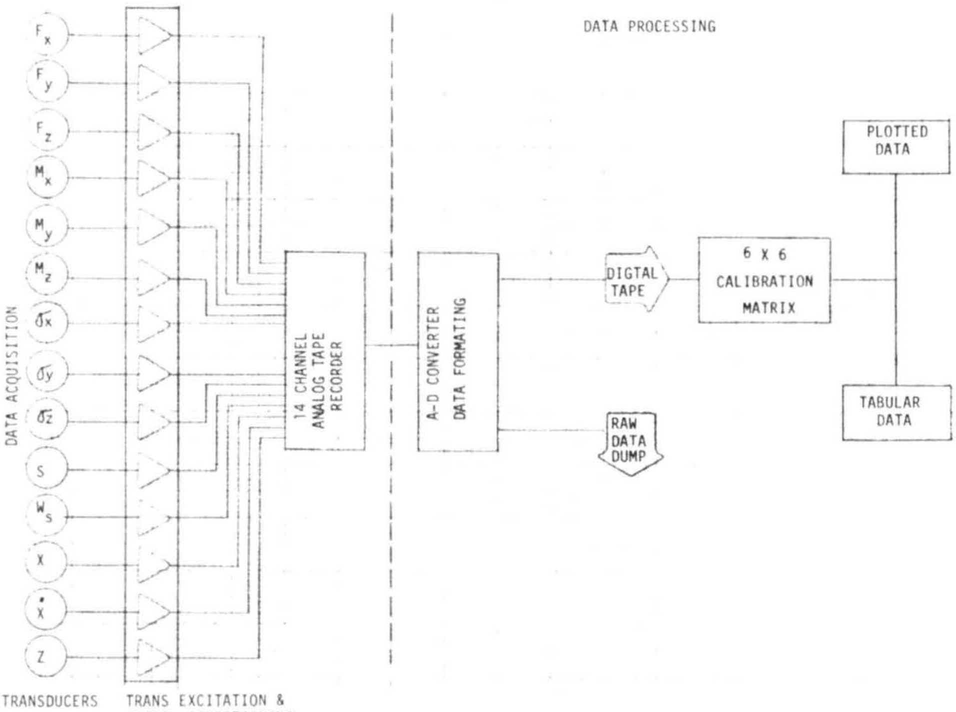


FIGURE 2
TIRE FORCE MACHINE DATA ACQUISITION AND PROCESSING

The specifications and testing capabilities of the flat surface tire force machine are shown in Table I.

Table I

Tire Force Machine Specifications

Velocity	0.25 ft/sec – Constant Speed
Total Length	20 ft.
Useable Length	18 ft.
Drive	7 in. Diameter Hydraulic Cylinder

Tire Test Capability

Max. Tire Size	56 x 16 – 56 in. Outside Diameter
Min. Tire Size	6.00 x 6 – 17 in. Outside Diameter
Max. Vertical Load	80,000 lbs.
Max. Camber Angle	±20 Degrees (2 Deg Increments)
Max. Slip Angle	±90 Degrees (Infinitely Variable)
Max. Tire Velocity	0.25 ft/sec
Max. Brake Torque	50,000 ft-lbs

Data Recording

Signal Filtering	3 HZ – Low Pass
Test Monitor	8 Channel Strip Chart Recorder
Data Sampling Rate	Variable
Tape Unit	14 Channel Bell & Howell Data Tape VR-3700B

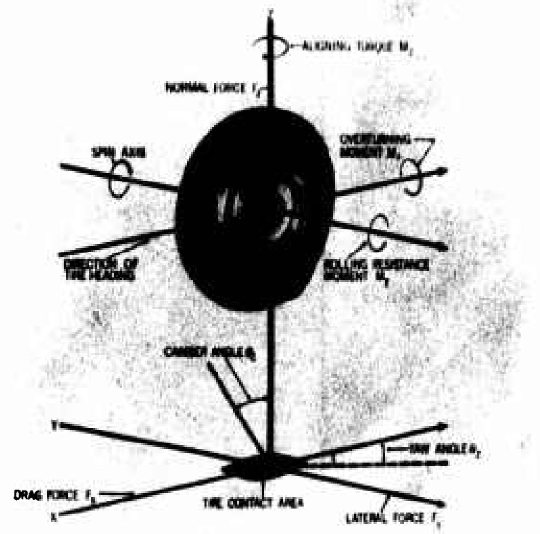
Data Processing

Data General Corp. Nova 2/10 Digital Computer

Output Parameters

Lateral Force, Fy
Normal Force, F_Z
Tractive Force, F_X
Rolling Resistance Moment, My
Overturning Moment, M_X
Self Aligning Moment, M_Z
Effective Rolling Radius, R_e
Percent Slip, s
Table Position, x
Normal Contact Pressure, σz
In-Plane Footprint Shear Stress, $\sigma x, \sigma\ y$
Wheel Angular Position, θ

Mechanical property data, which is a function of one or more of the output parameters, consists of such items as load vs. deflection data, tractive force vs. tire slip ratio, obstacle engulfment properties, footprint areas, tire contact pressure distribution, lateral force and self-aligning torque. All data compiled on both the tire force machine and 120 inch programmable dynamometer conforms to the SAE tire axis system. The rolling tire forces and moments according to the SAE tire axis system is shown in Fig. 3.



ROLLING TIRE FORCES AND MOMENTS

FIGURE 3

Load vs. deflection tests are performed in three directions, namely vertical, lateral and fore-aft. Tire spring rates and hysteresis are calculated for all three modes of deflection. In addition, the effective coefficient of friction, the vertical sink and the center of pressure shift are calculated for the lateral and fore-aft load vs. deflection tests. Figures 4, 5, and 6 are typical load vs. deflection plots from the flat surface tire force machine.

Footprint net and gross areas and footprint pressure distribution curves are obtained at various vertical loads and tire inflation pressures. The footprint pressure distribution is obtained via an xyz triaxial sensor developed by Photolastic Inc. (see Fig. 7). This device measures two in-plane shear stresses and the normal stress in the tire contact area. Figures 8, 9, and 10 show, respectively, tire in-plane shear parallel to tire rotation, tire in-plane shear perpendicular to tire rotation, and tire stress normal to the table surface.

Tractive force vs. tire slip ratio is obtained by use of an electro hydraulic control system which modulates the brake pressure to obtain a prescribed amount of circumferential slip. This data is obtained as a function of tire load, inflation pressure and tire steer angle. A plot of tractive force vs. tire slip ratio is shown in Fig. 11.

Obstacle engulfment properties are obtained by rolling the tire over various simulated "potholes" and obstructions that can be placed on the tire force machine table. The tire inflation pressure and vertical load is varied when conducting a sensitivity analysis of the vertical reaction

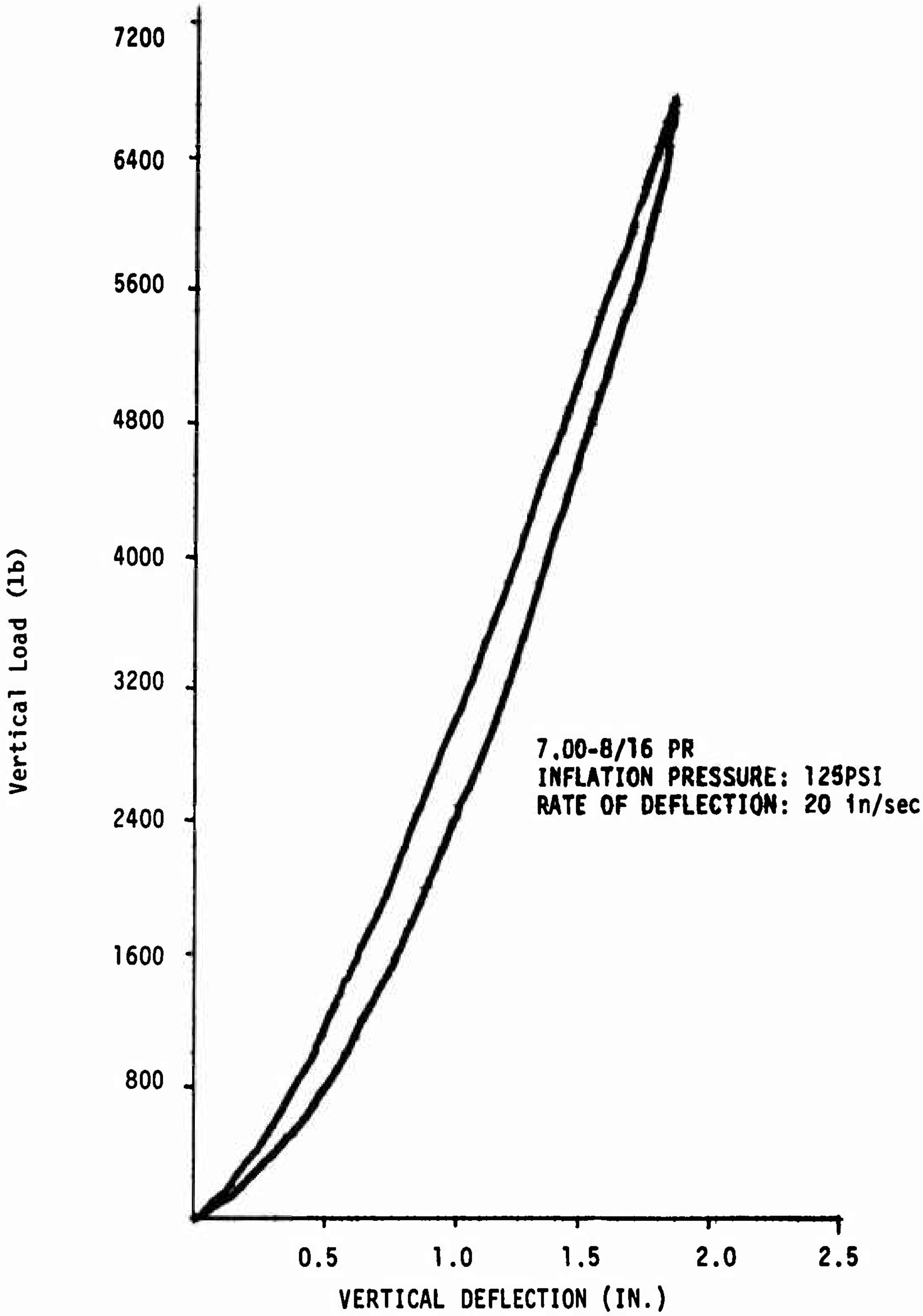


FIGURE 4 VERTICAL LOAD VS VERTICAL DEFLECTION

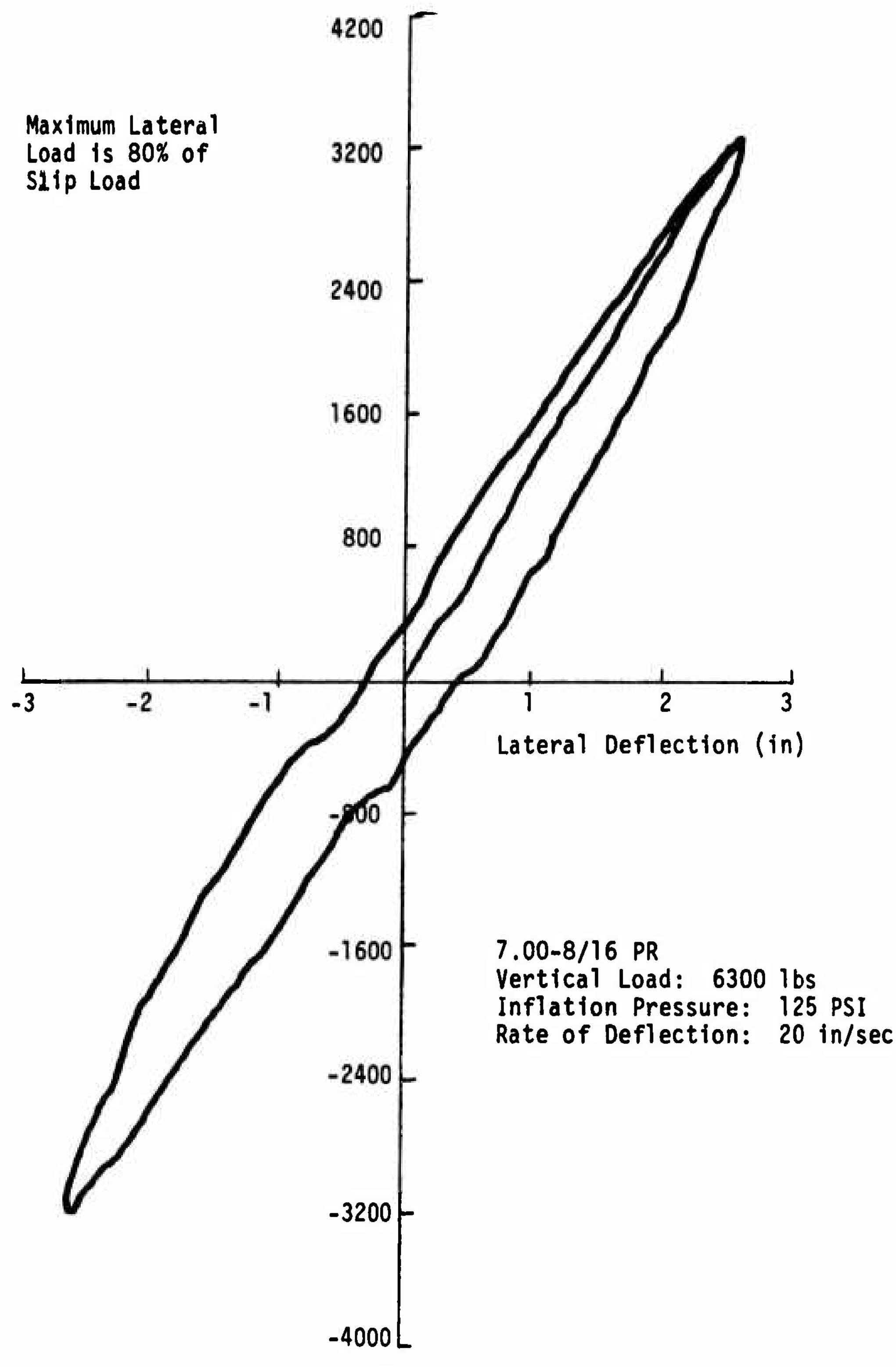


FIGURE 5 LATERAL LOAD VS LATERAL DEFLECTION

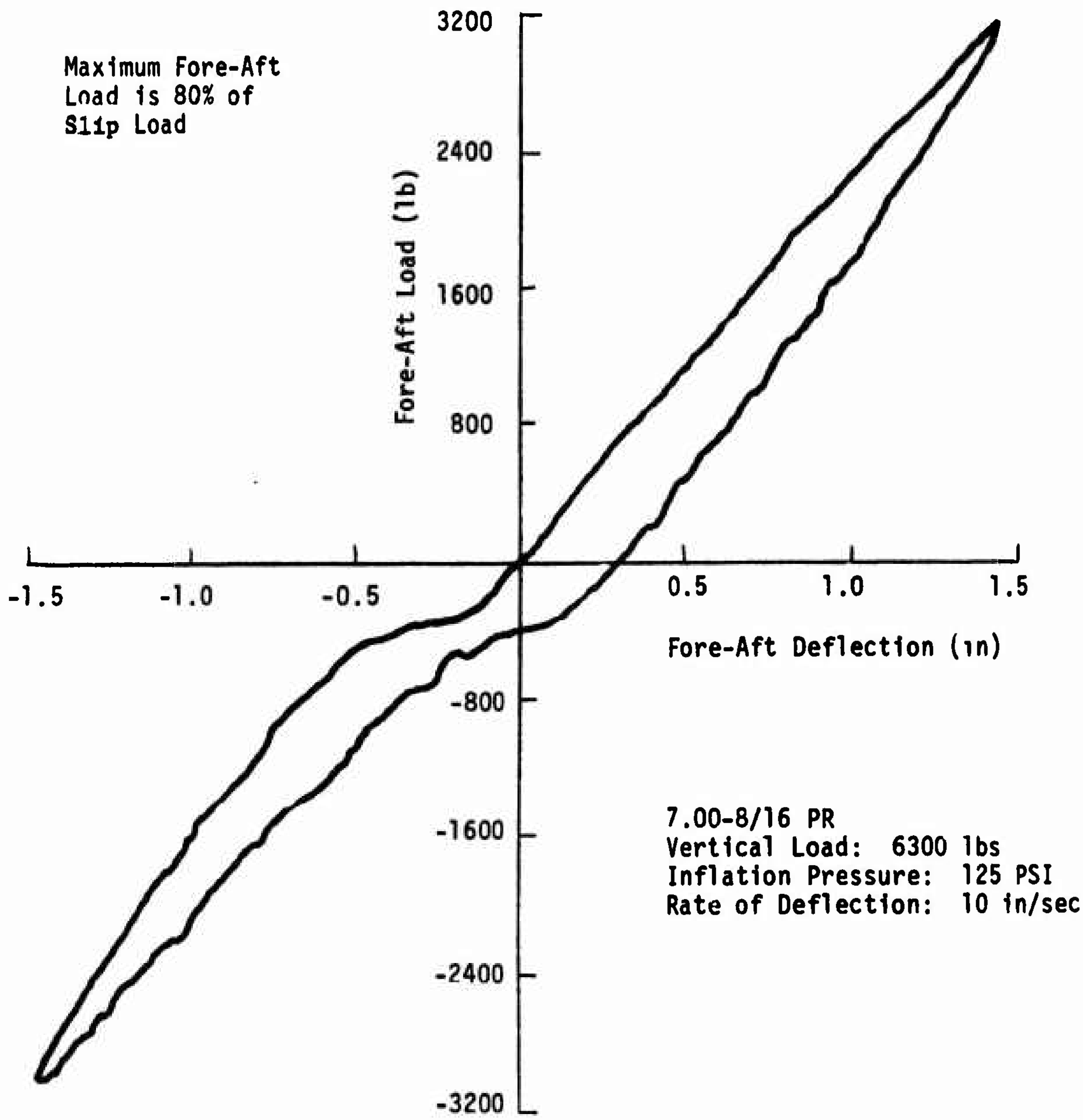


FIGURE 6 FORE-AFT LOAD VS FORE-AFT DEFLECTION

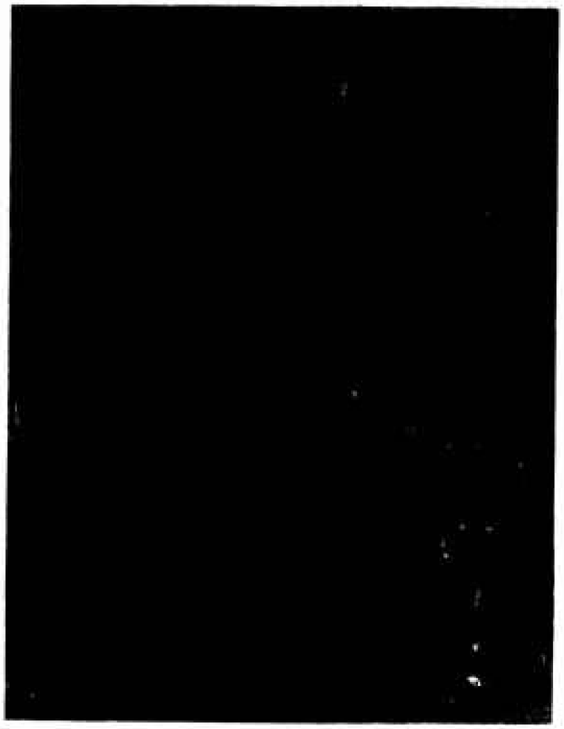
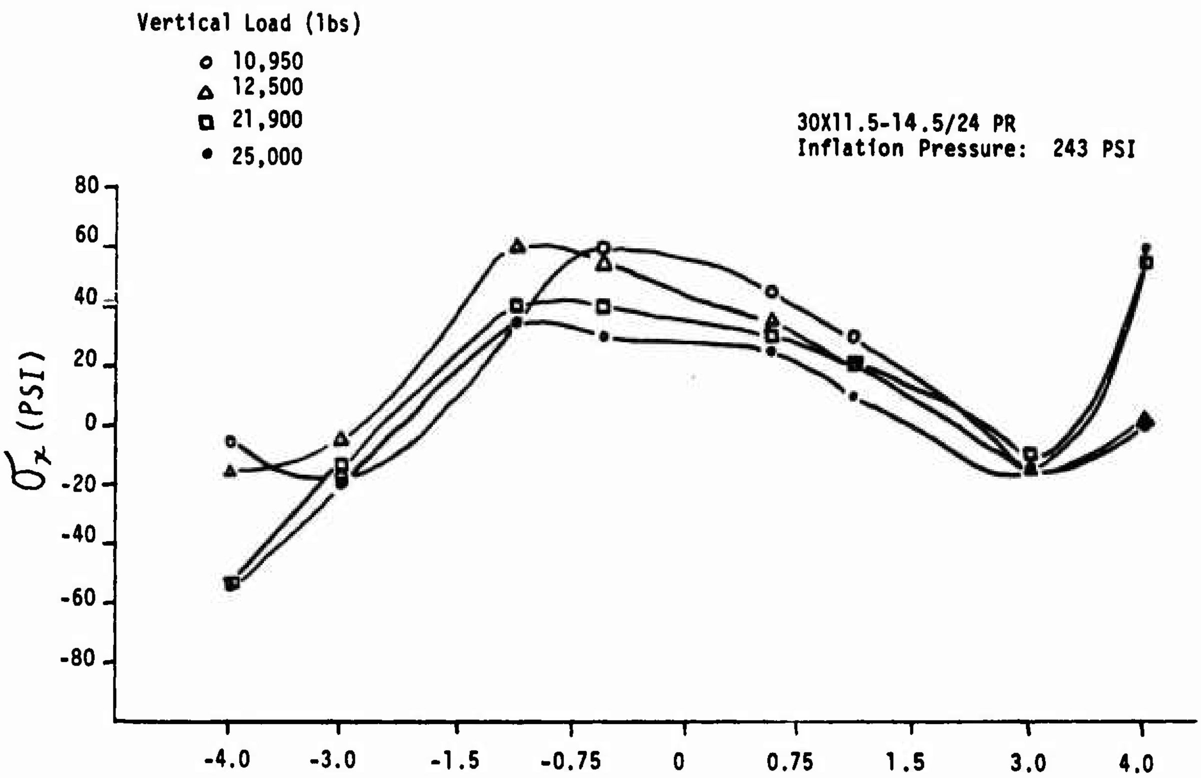


FIGURE 7 XYZ Triaxial Stress Transducer



Transducer location from tire center line (in)

FIGURE 8 TIRE IN-PLANE SHEAR STRESS–PARALLEL TO TIRE ROTATION

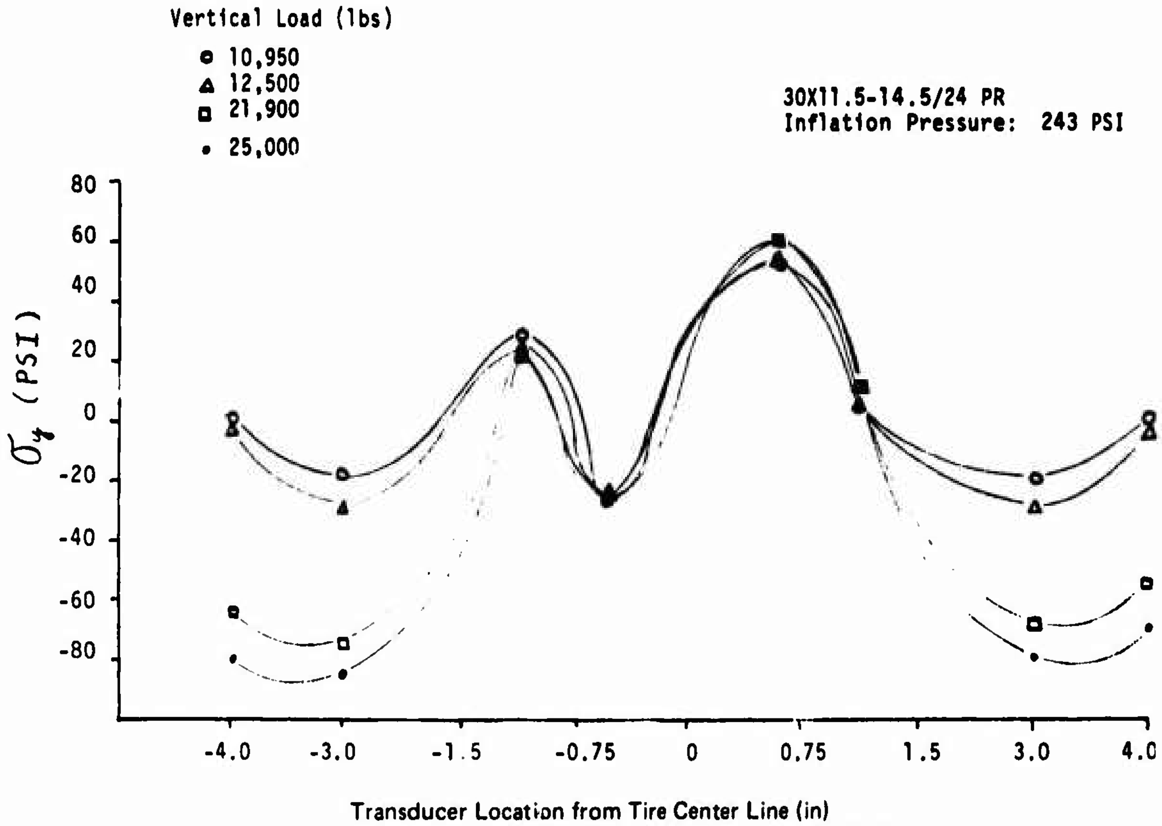


FIGURE 9 TIRE IN-PLANE SHEAR STRESS—PERPENDICULAR TO TIRE ROTATION

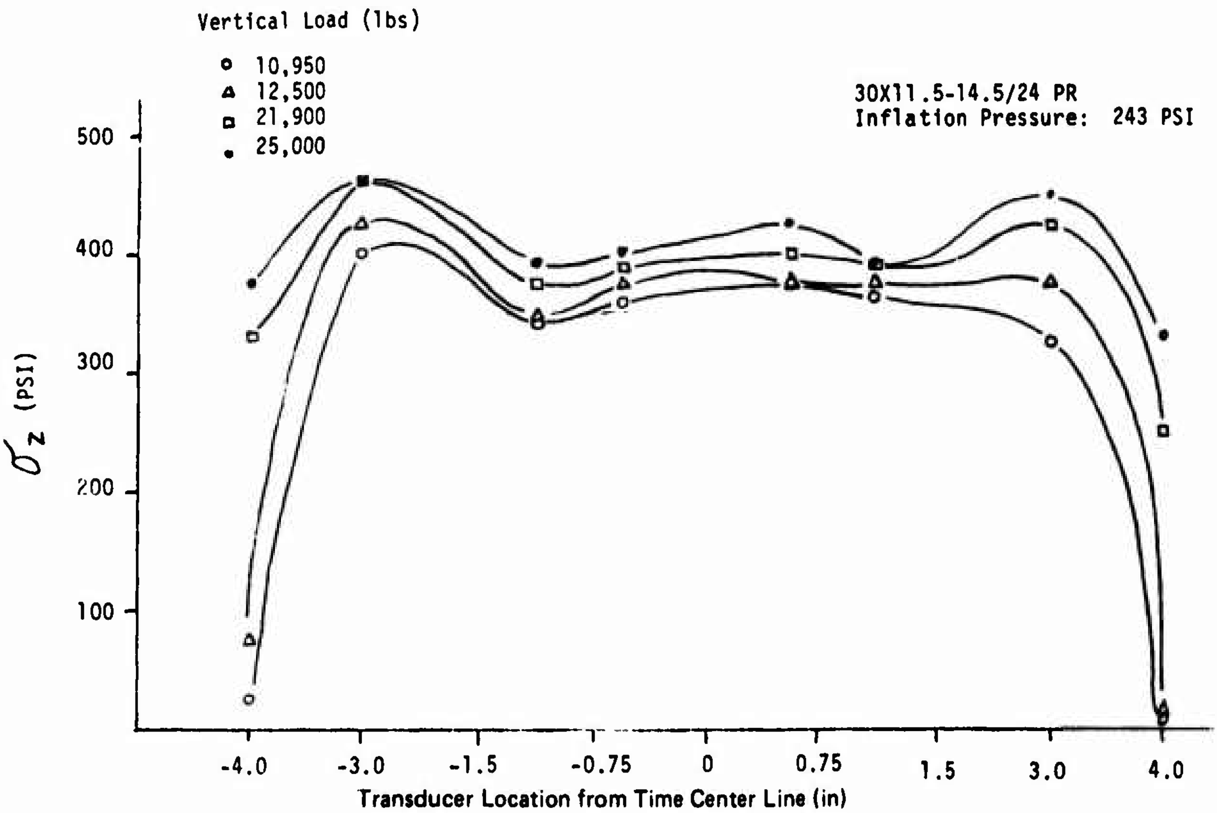


FIGURE 10 TIRE NORMAL STRESS

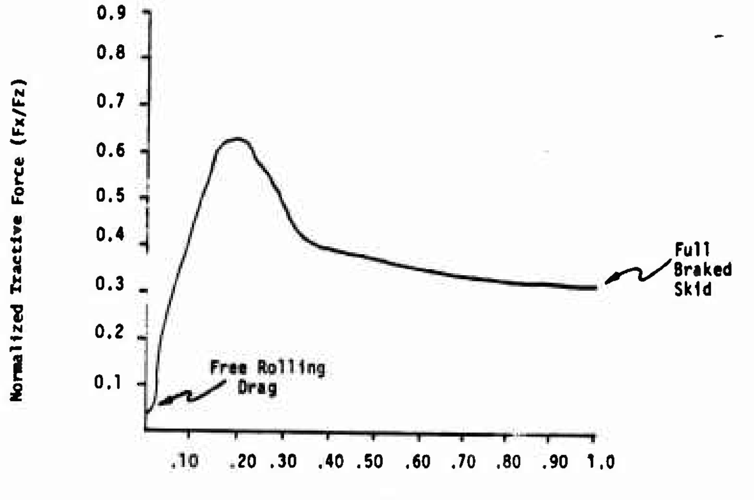


FIGURE 11 NORMALIZED TRACTIVE FORCE VS TIRE SLIP RATIO

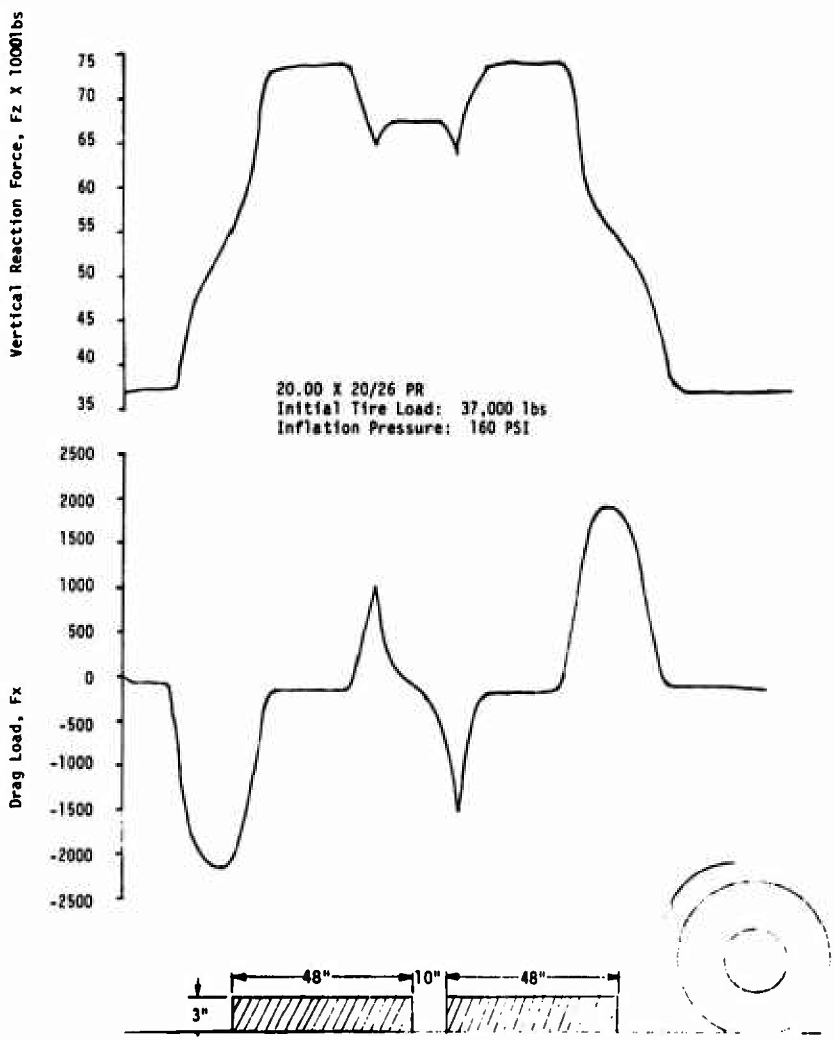


FIGURE 12 REACTION FORCES DURING OBSTACLE ENGULFMENT TESTS

force and the drag force acting on the tire assembly as the tire rolls over the simulated obstacles. Fig. 12 shows the vertical reaction and drag force developed during an obstacle engulfment test of a 56 inch outside diameter tire tolling over a 3 inch obstacle with a 3 inch deep, 10 inch wide "pothole".

Lateral force and self-aligning torque are two of the more important tire mechanical properties. They play a major role in providing vehicle directional control and dynamic stability of landing gear. These two mechanical properties are studied at various values of tire vertical load, tire inflation pressure, tire slip angle, tire forward velocity, and carcass and/or contained air temperature. The influence of surface pavement and surface contamination on these properties are also measured. Typical lateral force carpet plots and self-aligning torque carpet plots as a function of tire vertical load and tire slip angle are shown in Fig. 13 and Fig. 14, respectively.

Various other tests are conducted on the flat surface tire force machine. One of these involves measuring the normal stress at the tire tread and carcass interface when operating on flat and curved surfaces. The normal stress is measured by embedding stress transducers under the tire tread during a retreading process. Typical tire stress transducers and a cross section of a small aircraft tire are shown in Fig. 15. Rolling simulation on various curved surfaces is accomplished by rolling tires over arcs constructed of hardwood and clamped to the tire force machine surface. Conducting all curved surface stress measurements on the tire force machine eliminates the need to transport the tire/wheel assembly to the various dynamometers. It also eliminates the variation of the various load and load measuring systems. Fig. 16 shows an instrumented tire mounted on the tire force machine and rolling on a simulated 84 inch diameter dynamometer during stress measurement recordings.

Data from these tests indicates that the normal stress increases on surfaces with smaller radii of curvature. The standard procedure to compensate for dynamometer flywheel curvature is to increase the tire inflation pressure. This is done to duplicate flat surface tire deflection. However, analysis of this data indicates that this method is incorrect and that tires are being "over tested". This appears to be true, in that tread separation failures occur

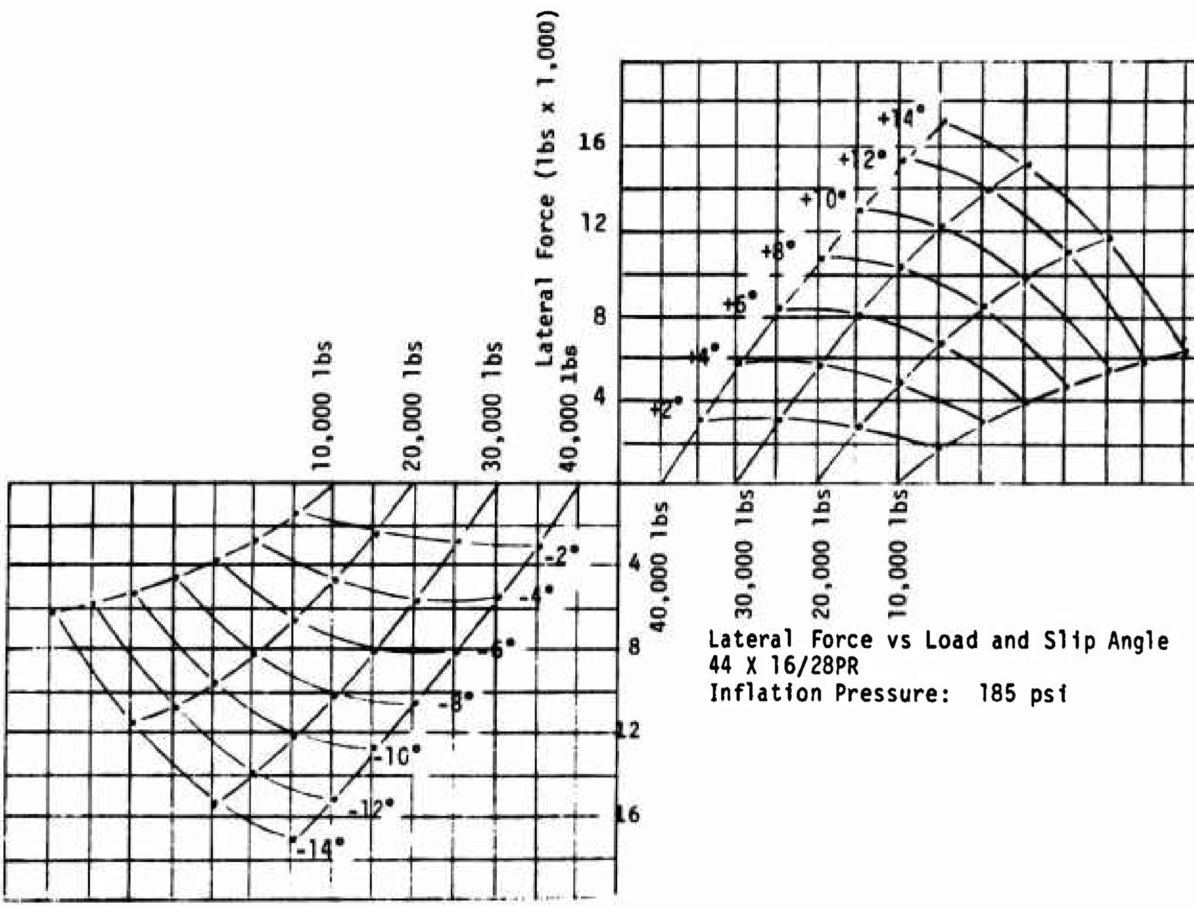


FIGURE 13 AIRCRAFT TIRE LATERAL FORCE CARPET PLOT

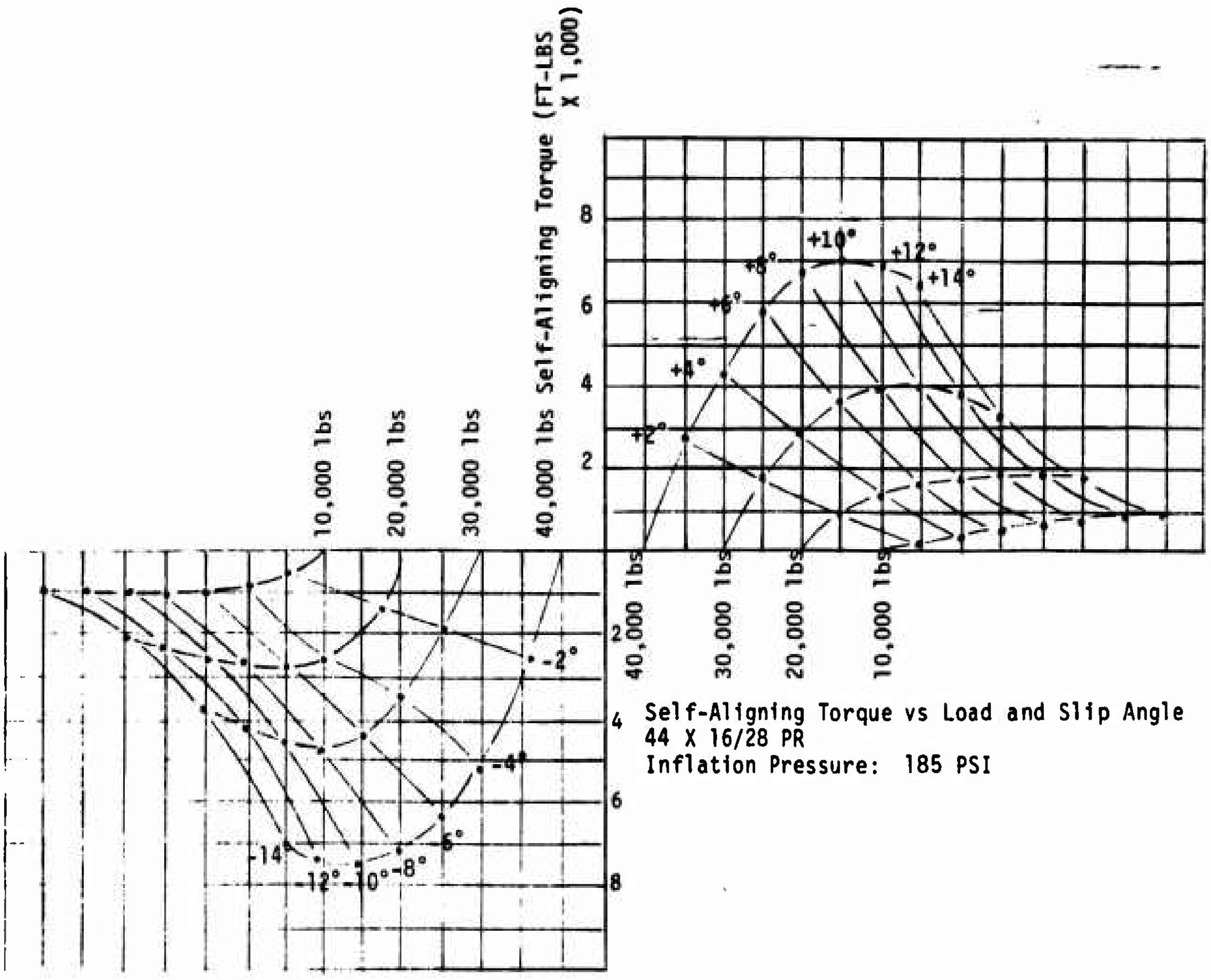


FIGURE 14 AIRCRAFT TIRE SELF-ALIGNING TORQUE CARPET PLOT

frequently in the laboratory whereas replacement of a tire in the field before tread wear out is generally due to cuts and tears in the tread and shoulder region. A stress carpet plot for a small aircraft tire is shown in Fig. 17, which indicates that duplication of the normal stress experienced by a tire operating on a flat surface is achieved by reducing the vertical load on tire.

Various other load and/or deflection correction methods are being investigated. All correction methods are then tested by subjecting new tires with full skid depth and new tires with the tread buffed to a minimum skid depth to taxi take off tests until failure occurs. Tires with full and minimum skid depth are tested to ascertain the influence of tread thickness in new tire qualification tests. Tires tested per a certain curvature adjustment procedure are taken from the same production lot and then screened by holographic NDI to establish a quality control acceptance criteria. Based upon the dynamometer test results, a relationship between tire stress levels and dynamometer diameter for various sizes and types of aircraft tires will be

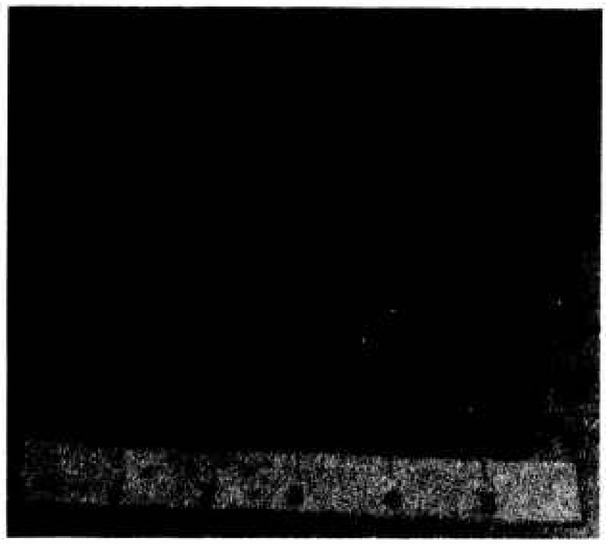


FIGURE 15 SMALL AIRCRAFT TIRE AND STRESS TRANSDUCERS

FIGURE 16 MEASURING STRESS NORMAL TO TIRE TREAD AND CARCASS

established. Ultimately, a change in the military tire qualification specification will be recommended with emphasis on the procedure to evaluate tread retention, to compensate for dynamometer flywheel curvature, and on the number of tires required to meet the qualification specifications.

120 INCH PROGRAMMABLE DYNAMOMETER

The advanced, programmable dynamometer incorporates a six component force measuring system similar to the tire force machine with six load cells arranged in a rigid structure containing the tire/wheel assembly and attached to the primary carriage by flexure struts. This dynamometer has the capability of programmable yaw, camber, vertical load, vertical sink rate, wheel velocity and wheel acceleration. This allows for an accurate simulation of the forces and moments an aircraft tire experiences due to ground loading and maneuvers. A photograph of a tire undergoing testing on the programmable dynamometer is shown in Fig. 18. Program control is accomplished by solid state electronics and PDP 11 analog computers. A summary of the available test parameters of the Programmable Dynamometer is shown in Table II.

The programmable dynamometer can measure all the tire properties that the tire force machine can measure, and can include the effects of dynamic variation of load and tire rotation. Thus, a correlation between static, quasi-static, and transient tire properties can be made.

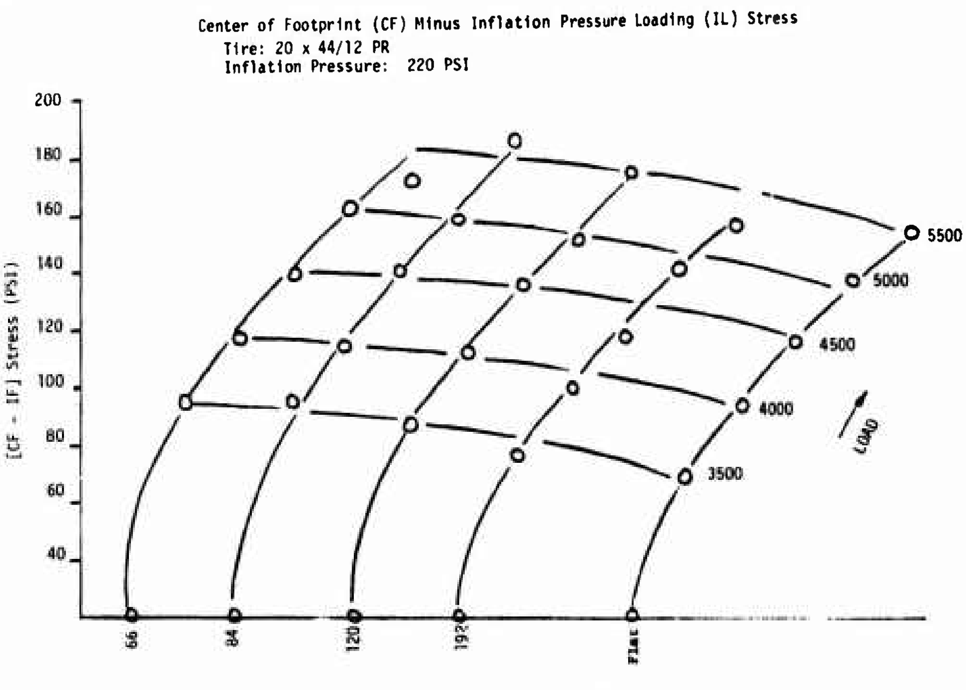


FIGURE 17 NORMAL STRESS VS SURFACE CURVATURE AND LOAD

FIGURE 18 TIRE UNDERGOING TEST ON MODIFIED DYNAMOMETER

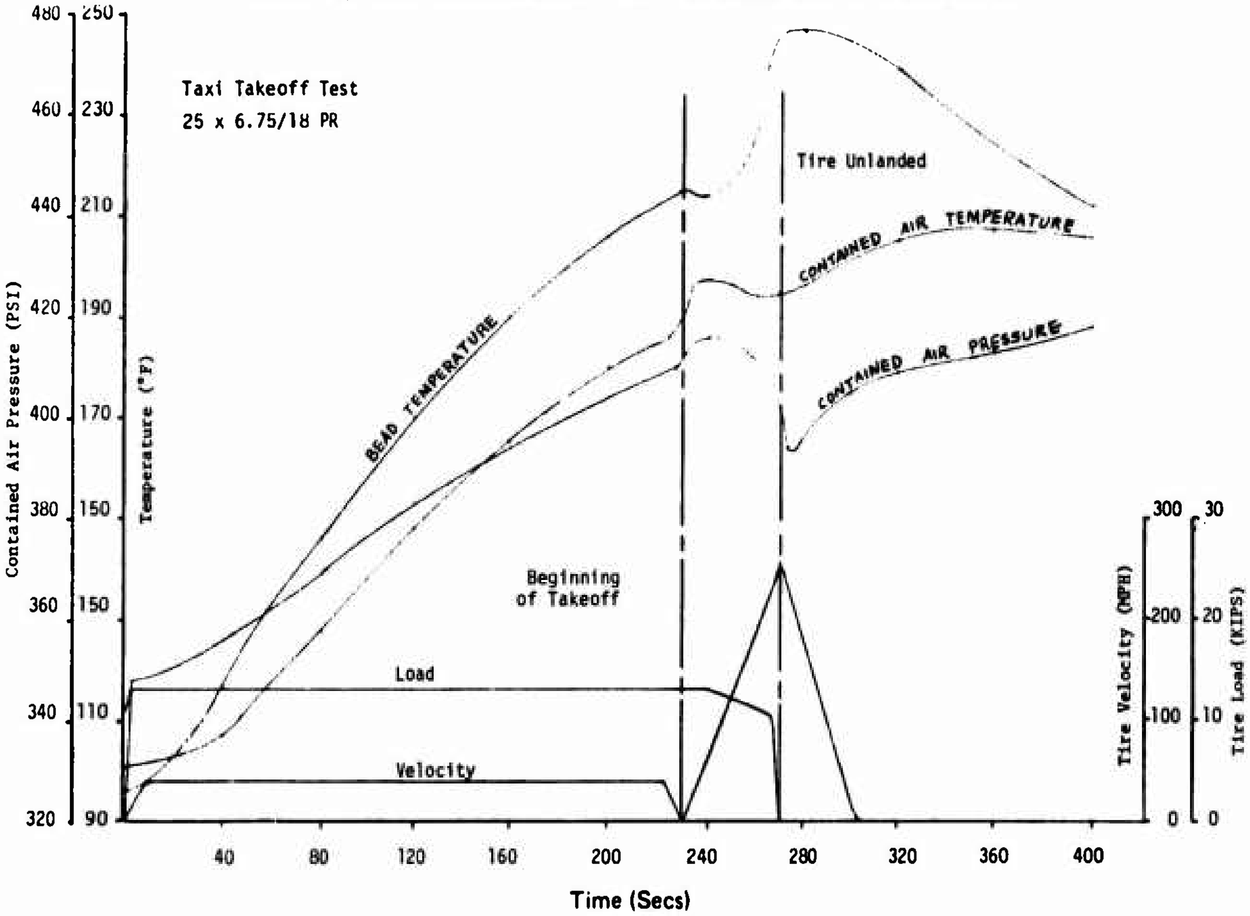


FIGURE 19 TAXI – TAKEOFF LOAD, SPEED, AND TEMPERATURE PROFILE

Table II

Dynamometer Specifications

Velocity	350 MPH
Flywheel Diameter	10 ft.
Max. Acceleration	24 ft/sec^2
Drive	3 Reliance DC Motors, 1150 HP

Tire Test Capability

Max. Tire Size	56 x 16 - 56 in. Outside Diameter
Min. Tire Size	18 x 5.5 - 18 in. Outside Diameter
Max. Vertical Load	100,000 lbs.
Max. Vertical Stroke	14 in.
Max. Sink Rate	60 in/sec
Max. Yaw	±20 Degrees
Max. Cyclic Yaw	±4 Degrees at 2 Hz
Max. Camber	±20 Degrees
Max. Cyclic Camber	±3 Degrees at 2 Hz

Data Recording

Contained Air Pressure	500 psig
Contained Air Temperature	0-300^{o}F
Forces in 3-Directions	*
Moments about 3-Axes	*

*Data is sampled 20 times per second and stored on magnetic tape.

In addition, the effects of carcass temperature on tire lateral properties can be measured on the programmable dynamometer. The internal stress generated in a tire during the cyclic contact of the tire with the surface pavement produces heat build up. The temperature of an aircraft tire after taxiing from the hangar area to the runway is generally in the vicinity of 200 degrees Fahrenheit. A plot showing the tire load, tire velocity, contained air pressure, contained air temperature and bead temperature during a taxi take off is shown in Fig. 19. The lateral force (F_y) available during take off, therefore, is that force which is generated in tires with an average temperature in excess of 200 degrees Fahrenheit. A carpet plot of lateral force at 5 MPH and at various vertical loads and slip angles is shown in Fig. 20 for a small aircraft tire with a carcass temperature of 90^{o}F and 220^{o}F.

The mechanical properties of retreaded aircraft tires are also being measured at the Air Force Flight Dynamics Laboratory. Preliminary results have indicated that the self-aligning torque and lateral force of retreaded aircraft tires are less than that exhibited by non-retreaded aircraft tires. It is not known if this is a carcass or tread related phenomenon and will be further investigated. Carpet plots showing a comparison of the lateral force and the self-aligning torque of a retreaded and non-retreaded aircraft tire at the speed of 75 miles per hour are shown in Fig. 21 and Fig. 22.

Frequency response tests are conducted on the programmable dynamometer to study the transient behavior of aircraft tires, which is important in studying problems dealing with landing gear stability. One of these tests is a sinusoidal yaw test which is conducted to measure tire

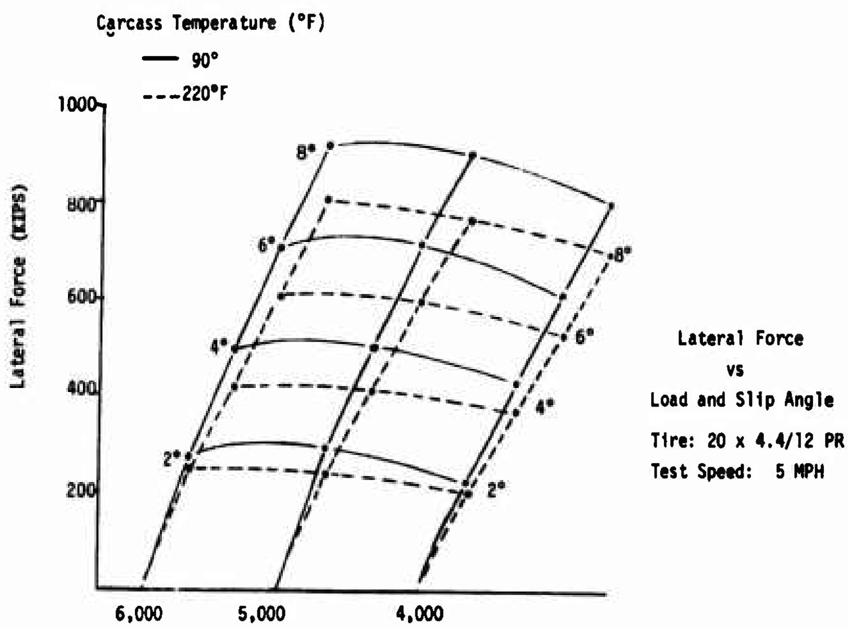


FIGURE 20 EFFECT OF TEMPERATURE ON LATERAL FORCE

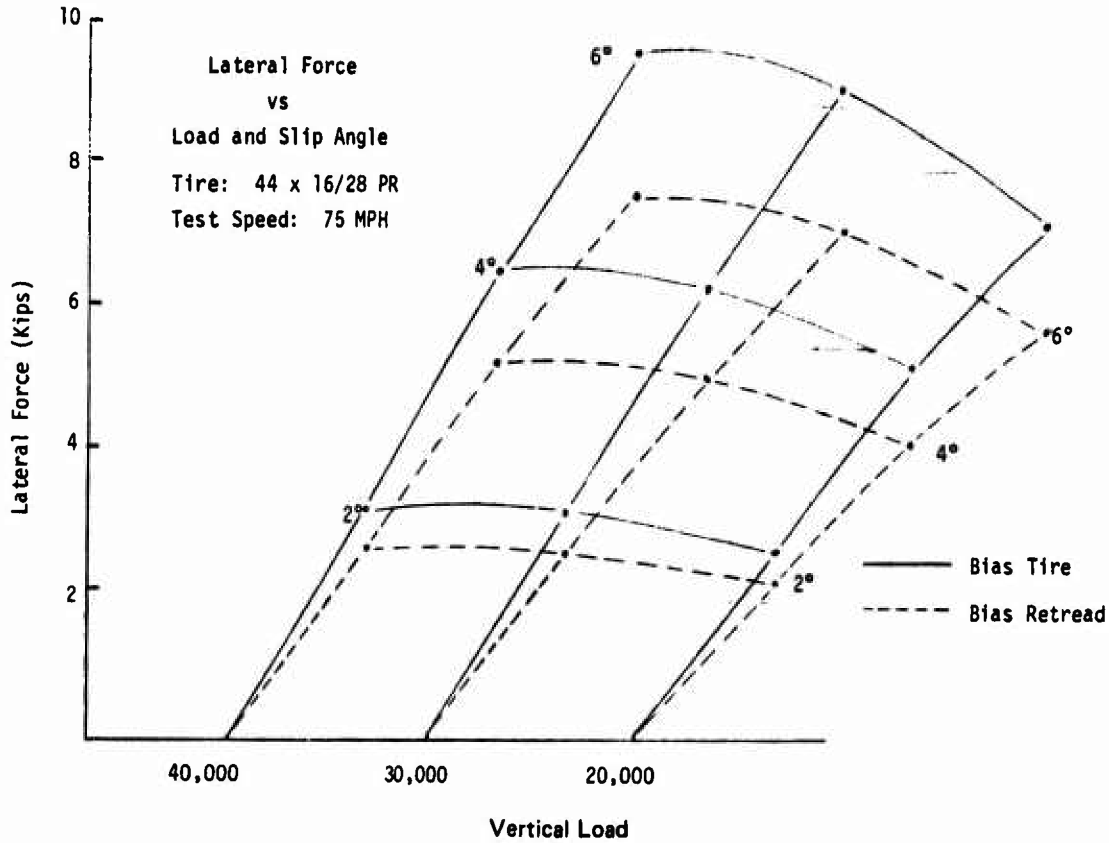


FIGURE 21 EFFECT OF RETREADS ON LATERAL FORCE

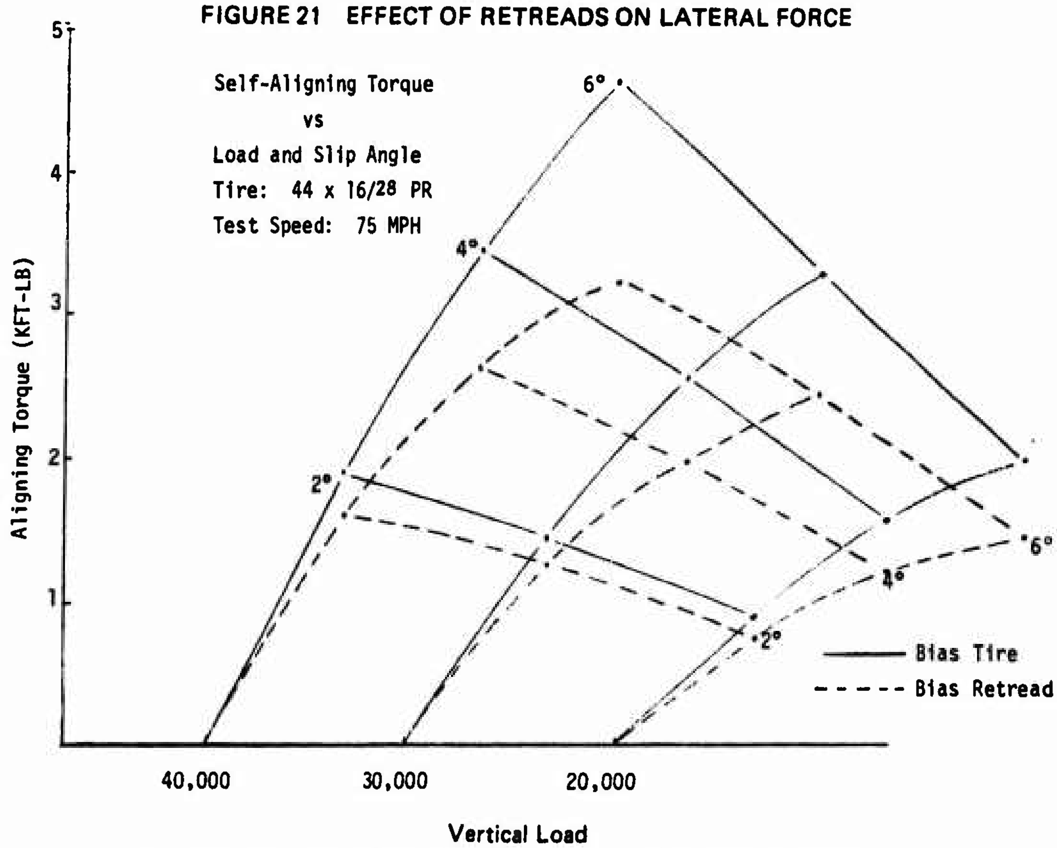


FIGURE 22 EFFECT OF RETREADS ON SELF-ALIGNING TORQUE

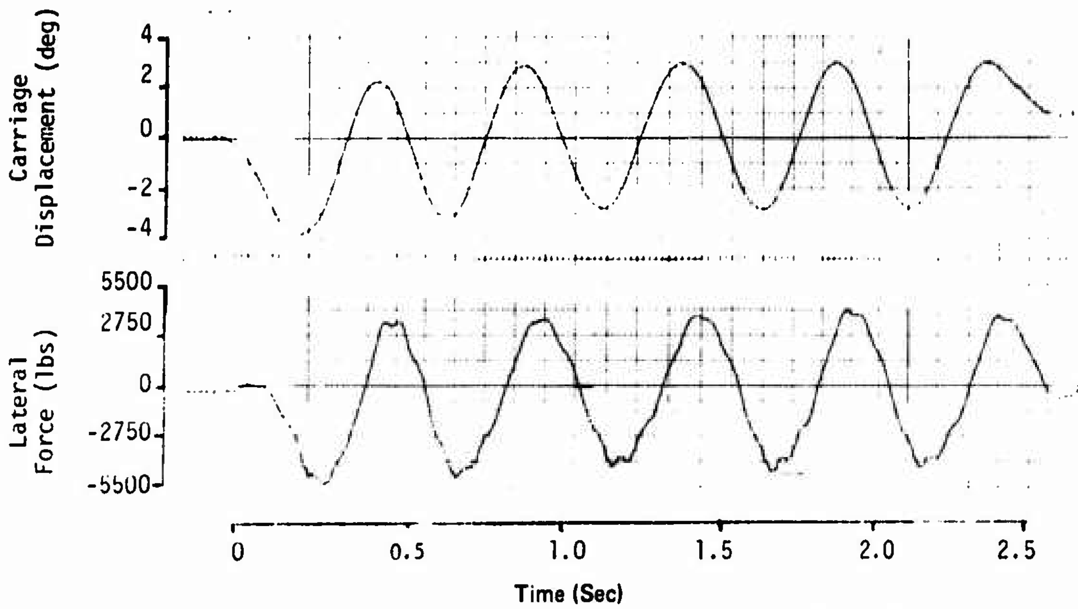


FIGURE 23 LATERAL FORCE RESPONSE TO SINUSOIDAL INPUT

properties important for shimmy studies. The forces and moments that are of primary interest in shimmy studies are lateral force (F_Y), overturning moment (M_X) and self-aligning torque (M_Z). The results of these tests show that the tire does have a response lag which is an important factor in a shimmy analysis. Fig. 23 shows a 2 hz, ±3 degree angular displacement of the dynamometer carriage and the resulting lateral force response.

CONCLUSION

Knowledge of mechanical properties of aircraft tires is necessary in the design of landing gear and in the prevention and solution of landing gear problems. Data from the flat surface tire force machine and the 120 inch programmable dynamometer at the Air Force Flight Dynamics Laboratory can be used to establish the operating characteristics of aircraft tires and to establsih new tire design criteria and qualification test procedures. The data can also be used to modify and improve analytical techniques for predicting the dynamic behavior of landing gear struts, brakes, antiskid systems, aircraft steering and, in general, overall aircraft ground handling performance.

QUESTIONS AND ANSWERS

Q: Jim, I'd like to ask a question if I could. Is the Facility open for visitors?

A: Yes, it is.

Q: Could you tell them maybe how they could make arrangements to get in?

A: The person to contact is a Mr. Aivars Petersons, and he can be reached at Area Code (513) 255-2663.

Q: Would you expand a little bit on the subject you introduced briefly about the difference in the force measurements on new tires and retreaded tires?

A: The tests we have done to date have indicated that retreaded tires exhibit lower cornering force and self-aligning torque than new tires of the same size, and from the same manufacturer. At this time, it is not known what creates the degradation of forces. It would have to be investigated further.

Q: You indicated that the stress for the curvature of the dynamometer has been normally taking the tire pressure rates in the tire up to higher pressure. What method are you recommending now?

A: Well, we're looking at various methods. One of the methods that I showed here was a load correction method and the stress curve that I showed had the center of pressure of the footprint shown at the various loads and at the various curvature of radii. What that indicates is that, in order to operate your tire at the same level of stress that would be seen on a flat surface, the proper procedure to use would be to decrease the load so that you would run at the same level of stress.

Q: The stress that you're measuring, is it the center line of the tire or the total tire?

A: We are measuring at various points along the periphery of the tire and the curves shown were an average of the readings from the stress transducers in the shoulder ribs.

Q: Isn't it also true in the tire central rim as well as the central group?

A: Yes, it is, the same thing can be found. It's just that the transducers in the outer ribs has a cleaner curve.

Q: Your stress levels are not in the carcass plies?

A: We are not measuring cord stress, if that's your question. We're measuring the stress that is perpendicular to the tire at the surface.

SIZE CRITICALITY STUDY IN NAVY AIRCRAFT TIRES

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INTRODUCTION

The U. S. Navy several years ago established the requirement for the Non-destructive Inspection (NDI) of rebuilt (retreaded) aircraft tires. The following study is part of an on-going program to determine the criticality of defects found during NDI and to establish appropriate rejection criteria for the aircraft tires. The Navy requires NDI on tires with a speed rating greater than 160 mph. The majority of these tires are used on fighter and attack type aircraft which have only a single tire on each main gear and either one or two tires on the nose gear (Figure 1). If one tire fails, there is the possibility of damage to the wheel and landing gear, foreign object damage (FOD) to wings and fuselage, and the possibility of losing the aircraft and pilots.

The Navy aircraft tires are exposed to a more hostile environment than aircraft in other services or the commercial sector, in particular, the requirement for aircraft carrier operations of catapult takeoffs and carrier landings, more aptly described as controlled crash. Additionally, all Navy fields have arrestment cables of 1-3/8" diameter that are crossed during takeoffs and landings (Figure 2).

Therefore, this study becomes very important if it prevents the loss or damage to one aircraft due to a faulty tire. The defects to be examined are separations or disbonds as determined by holographic nondestructive testing. It is accepted general knowledge that separations in an aircraft tire will propagate. We wanted to determine the criticality of these separations: at what rate do the separations grow, at what size will the separations be detrimental to the tire integrity, and if there are locations in the tire where separations are more critical.

EXPERIMENTAL

The aircraft tires used in this study are the 26x6.6 size, 16 ply rating, Type VII used on the main landing gear of the Navy's F-8 aircraft. The tire is constructed with a reinforced tread, with the exact design varying with each manufacturer. The tire studied has two tread reinforcing plies approximately half-way between the bottom of the grooves and the carcass plies. The tires were obtained through the regular supply system or were rejects from a Navy contracted rebuilder. All the separations or defects were "natural", arising during the manufacture or the service life of the tires. None of the defects were intentionally made or programmed into the tires.

FIGURE 1
A-4 TAKING OFF

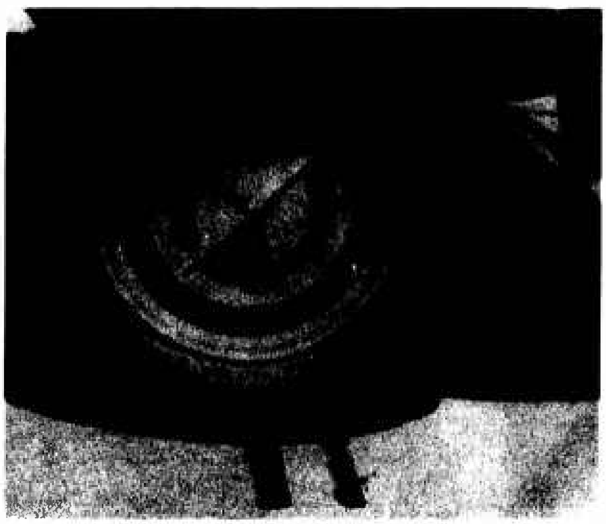


FIGURE 2
FIELD ARRESTMENT CABLE
NOTE DEFLECTION OF TRUCK TIRE

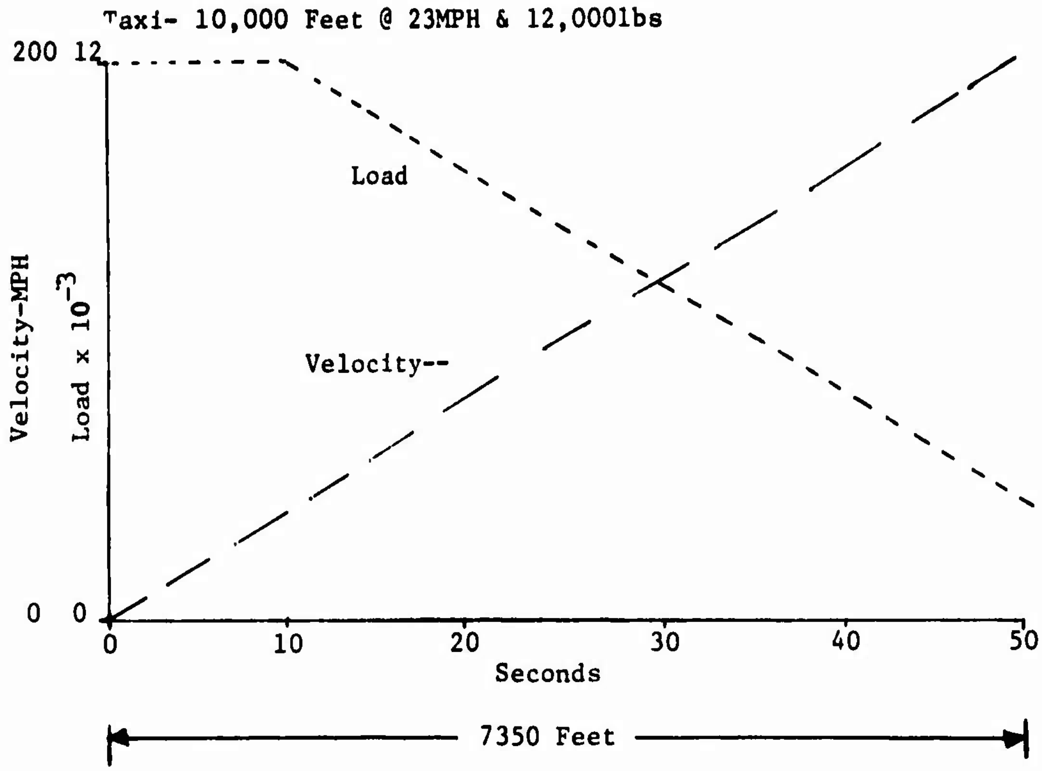


FIGURE 3 DYNAMOMETER TEST CYCLE

The tires were inspected with an Industrial Holographics Tire Analyzer equipped with a krypton laser. From the hologram, a map of each tire was produced. As each tire was inspected, the same map was used, to more easily see trend development.

The dynamic testing of the tires was performed on the 120 inch diameter dynamometer at Wright Patterson AFB (WPAFB). The test performed was the taxi-takeoff cycle as used by the Navy in Military Standards 26533 and 3383. The test consists of a taxi for 10,000 feet at 23 mph and 12,000 lbs. load. The tire is stopped and run through the simulated takeoff at 0 to 200 mph in 7,300 feet and load initially 12,000 lbs. decreasing to 1,200 lbs. at lift off (Figure 3). As part of the qualification tests the tires must successfully complete 50 cycles of the above test.

The tires were initially NDI and then sent to WPAFB for testing on the wheel. The tires were run through 25 cycles of the taxi-take-off (TTO), or until failure, with NDI being performed every 5 cycles. Those tires that had survived 25 cycles were then cycled to failure.

The following three examples serve to illustrate some of the different type of anomalies and locations across the tire tread.

The format is a map of the tire divided into four quadrants, starting at the serial number at 0° and preceeding clockwise around the tire. Anomalies detected during the initial inspection are marked on the grid in black; after 5 TTO cycles, in blue; and after 10 TTO cycles in red.

In the first example, Tire N8 (Figure 4) only one separation appeared initially. This separation was 3/4" diameter and located in the crown at 235°. After the first series of 5 TTO the initial separation had not grown, but the tire had developed three new separations of 3/8" diameter at 45°, 285°, and 360°.

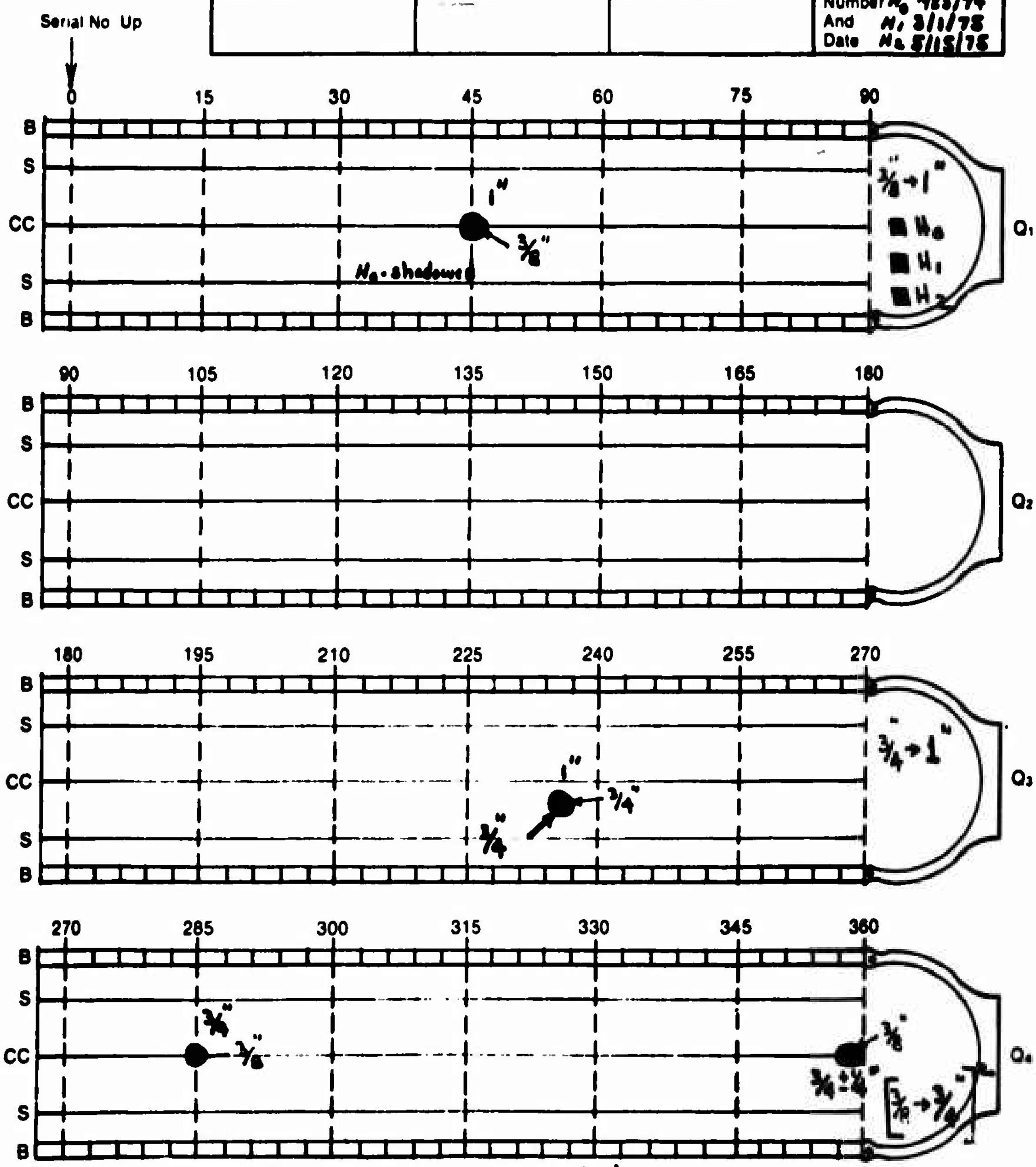
After 10 TTO cycles, the initial separation at 235° had grown to 1 inch and the other separations had grown to 3/4 inch and 1 inch. The testing was continued, and the tire eventually failed after 28 TTO cycles.

In the second example, tire N4 (Figure 5), only a weak area in the second quadrant showed initially. After the first series of 5 TTO cycles, the tire had developed numerous small separations in the shoulders ranging from 1/8 to 3/4 inch, and one area in shoulder, centered at 45°, that was characterized as "weak" but with no actual separations.

After the next series of 5 TTO, all separations had grown, one at 70° from 1/4 to 2-1/2 inches. The "weak" area at 45° had developed a series of 5 separations. The tire then failed on the 15th cycle of taxi-take-off, throwing the entire tread.

$\Sigma_0 - \Sigma_5 - \Sigma_{10}$

Customer: NAVY	Tire Class: Special Study ✓; Reject	Size: 26x6.6	House Number: N8
Mileage: $\Sigma_0 = 0$, $\Sigma_1 = 5$, $\Sigma_2 = 10$	Retread Number: R_1	Carrier: In; Out	Serial Number: 03703C30C-7-67
Date Received	Date Shipped	Shipper Number	Holograph Number And Date: H_0 4/23/74, H_1 3/1/75, H_2 5/15/75

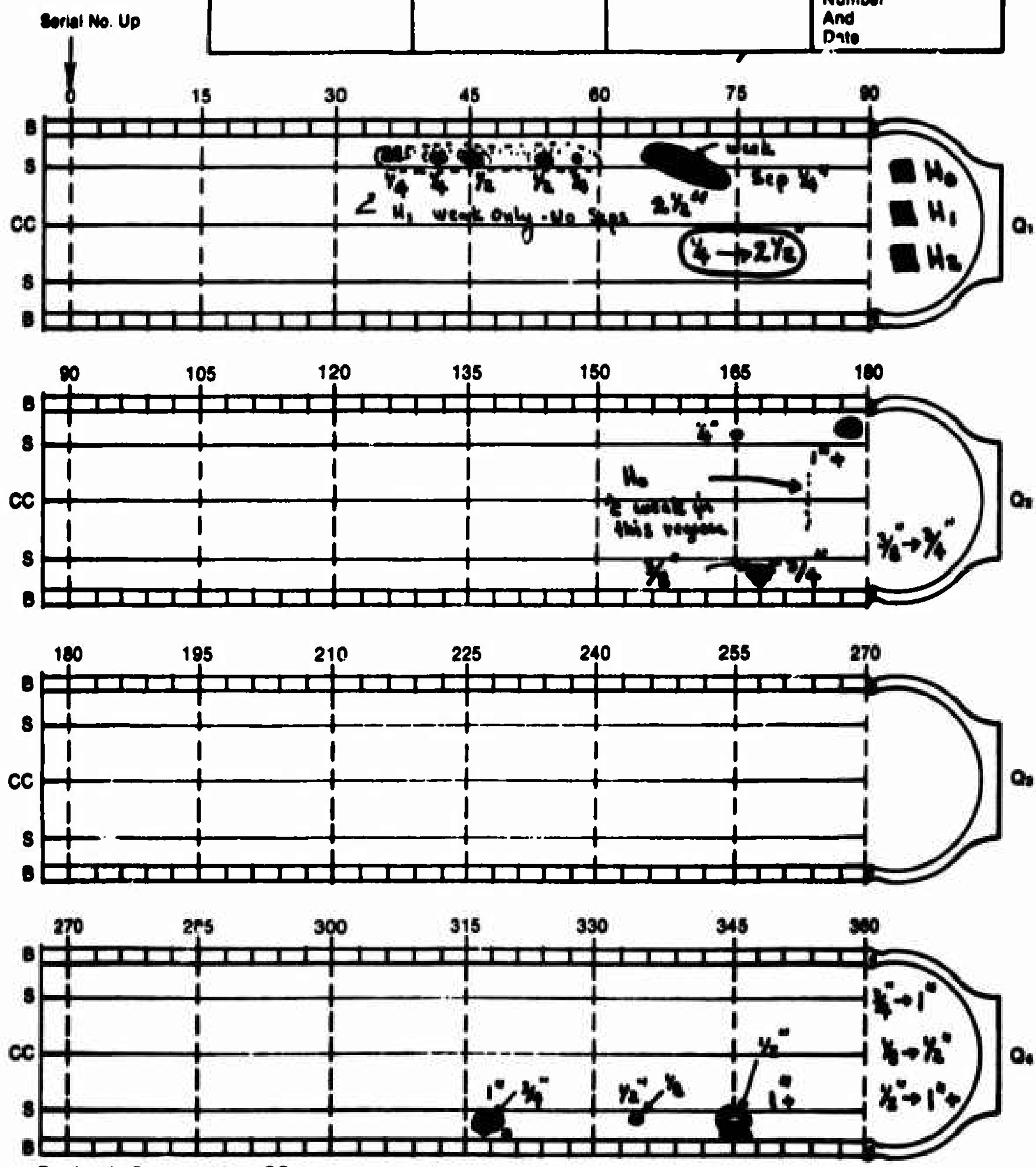


B - bead S shoulder CC crown center * shadowing

FIGURE 4

Σ_0 Σ_5 Σ_{10}

Customer		Size	House Number
NAVY	Tire O K / Special Study ✔ / Reject	26x6.6	N4
Mileage: 5 Taxi Takeoffs each $H_0 \to H_1 \to H_2$	Retread Number: R_0	Carrier In / Out	Serial Number: 40170125
Date Received	Date Shipped	Shipper Number	Holograph Number And Date

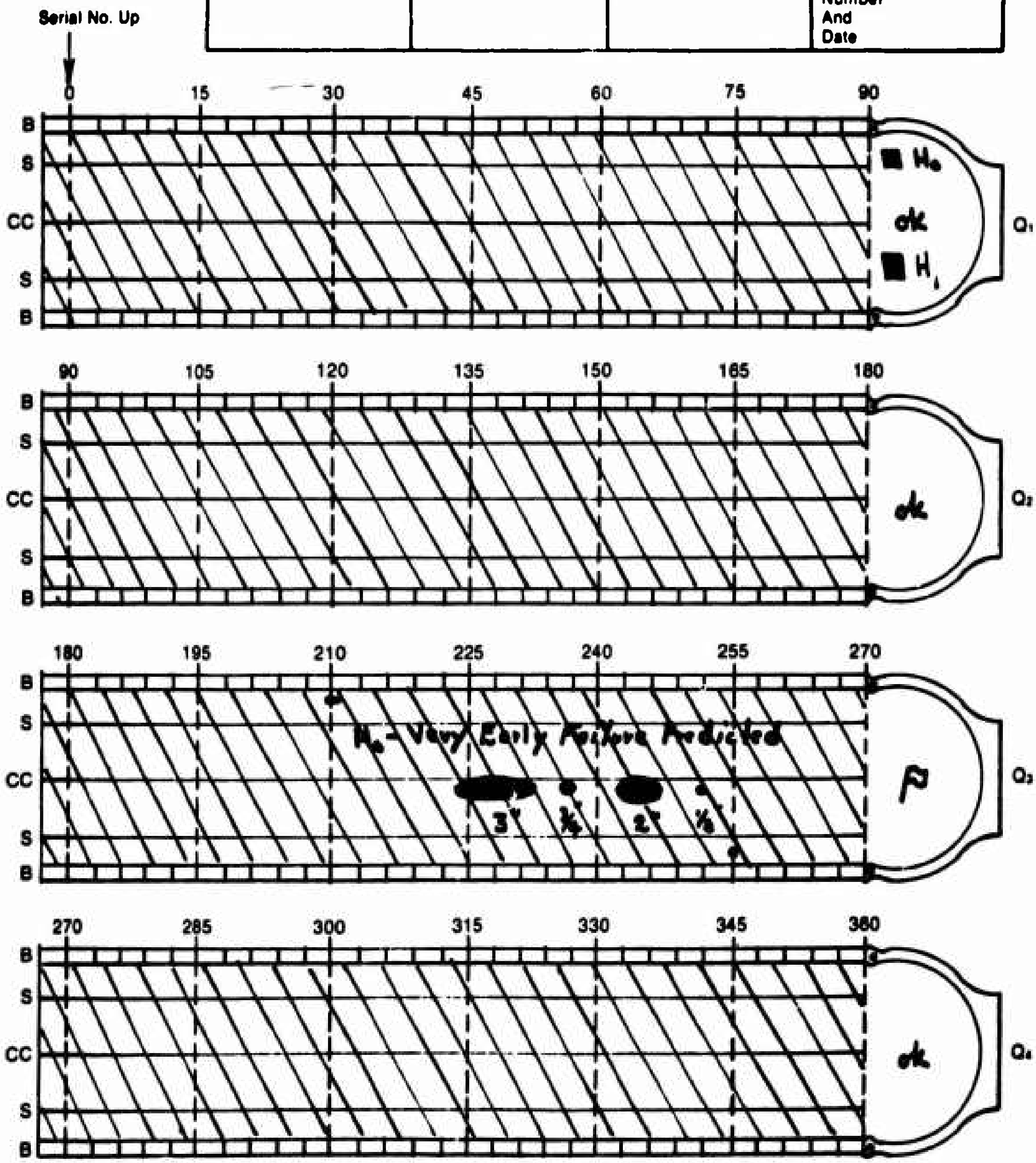


B = bead S = shoulder CC = crown center

FIGURE 5

FAILED $\Sigma_0 - \Sigma_8$

Customer	Tire O K / Special Study / Reject	Size	House Number
NAVY	Tire O K: Special Study: ✓ Reject:	26 x 6.6	N5
Mileage	**Retread Number**	**Carrier**	**Serial Number**
$H_0 \rightarrow$ S.T.T. $\rightarrow H_1$	R_1	In Out	9-66-87671
Date Received	**Date Shipped**	**Shipper Number**	**Holograph Number And Date**



B = bead S = shoulder CC = crown center

FIGURE 6

Centerline Separations

1/4" ——→ 1" 25 Taxi-Takeoff Cycles

1/8" ——→ 3/4" 25 TTO

"0" ——→ 1 3/4" 25 TTO

1/4" ——→ 1 3/4" 25 TTO

FIGURE 7 GROWTH OF CENTERLINE SEPARATIONS ON DYNAMOMETER TESTED TIRES

Shoulder Separations

3" ——→ 17" 5 Taxi-Takeoff Cycles

1/4" ——→ 7" 15 TTO

1/4" → 2.5" → 22" 10 TTO

FIGURE 8 GROWTH OF SHOULDER SEPARATIONS ON DYNAMOMETER TESTED TIRES

Skim Coat Separations

3" ——→ Failure 1 Taxi-Takeoff Cycle

1" ——→ 4" 10 TTO

4" ——→ Failure 1 TTO

1" + 1" ——→ 5" 5 TTO

5" ——→ Failure 2 TTO

FIGURE 9 GROWTH OF SEPARATIONS FROM SKIM COAT ON DYNAMOMETER TESTED TIRES

In the last example, tire N5 (Figure 6), the tire exhibited 4 large separations and was predicted to fail early in the testing. It did fail by throwing the entire tread during the first take-take-off cicle, indicated by the cross hatching through all the quadrants.

Again, the Military Specification requires the tires to complete 50 cycles of the TTO for qualification. If the above tires had been on an F-8 aircraft, the least that may have occurred is a premature tire change, a loss of maintenance manhours, and placing the aircraft in a down status. There is a wide range of scenarios possible when 10 to 15 pounds of rubber flies off at 100 mph or greater.

RESULTS

The study involved 16 tires. After 25 cycles the tires were cycled to failure. Of the 16 tires only two passed the required 50 cycles of the MS specification. One tire developed a separation on the 50th cycle but would be expected to have failed within the next two cycles.

Analysis of the tires and holograms show that the separations can be divided into three groups with respect to the propagations:

a. those centered in the crown,

b. those in the shoulder,

c. those on the skim coat of the first carcass ply.

The separations in each of these areas grew at differing rates.

The first area is defined loosely as under the crown but not extending to shoulders of the tire. We see growth of the separations is relatively slow and uniform in direction, progressing from 1/4 to 1 and 2 inches diameter after 25 TTO cycles (Figure 7). Even at 2 inches, a single separation did not cause a failure to occur.

When we examine the separations in the shoulder area, we see a dramatic change in the growth rate and shape of the separations. The separations grow to approximately 1 inch wide and progress lengthwise along the shoulder. The rate of propagation is considerably faster for separations originating in the shoulder (Figure 8), a 1/4 inch separation growing to 2.5 x 1 inch in 5 TTO vice 25 TTO for a centerline separation. When the shoulder separation became as long as 10 inches, failure of the tire was imminent.

In the two areas above, the separations were all in the carcass between 1st and 3rd carcass plies from the tread. The principal failure mode of the third type was propagation of separations on the skim coat of the 1st carcass ply (Figure 10). This was experienced on only one carcass manufacturer. The propagation rate was very rapid, for instance a 3 inch separation (Figure 9) causing the tread to strip in the last cycle.

The failure occurs faster since the separations were above the carcass plies, and no structural bonding or tread retention occurs from the carcass plies.

SUMMARY

As we have seen from the experiment on the indoor test wheel, separations in the tires will become larger and

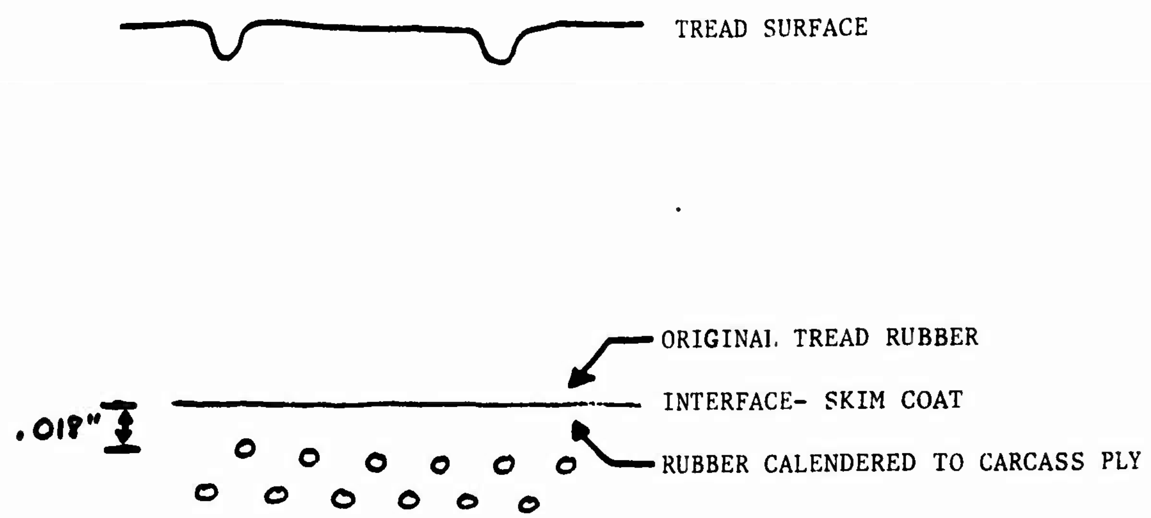


FIGURE 10 LOCATION OF SKIM COAT INTERFACE

ultimately result in tire failure by the stripping of the tread from the carcass.

Based on these studies, the Navy is examining the present rejection criteria with respect to the size and locations of the separations in the tire. Thus it may result in a maximum size of 1/2 inch diameter in the crown and 1/4" in the shoulders. Another criteria may be to reject manufacturer A's tires containing a 1/4 inch separation and manufacturers B, C, and D with 1/2 inch separation.

Further studies are being performed which will investigate:

- different tire sizes with their related test parameter;
- carcass manufacturer;
- carcass age.

The Navy is a firm believer of NDI and its capabilities of detecting tires that may fail prematurely. Initially, NDI was required for the Navy high-speed tires, rated over 160 mph. In the last several years, the Navy has required NDI on some critical low-speed tires.

QUESTIONS AND ANSWERS

Q: I have a question on this slide you have right here, the skim coat separations. What are the comparisons of these occurring in the tire region?

A: The skim coat I'm talking about is the skim coat on the first carcass ply. It is the rubber that is calendered to the first carcass ply. The separations occur at the rubber to rubber interface between the tread rubber components and the skim coat.

Q: In other words the first carcass ply means the ply next to the liner?

A: When I was referring to the first carcass ply I was indicating from the direction of tread area itself.

Q: We talk about it backwards.

A: Right. The tires that we investigated were of several different manufacturers and the number of actual carcass plys varies from manufacturer to manufacturer. The separations that we investigated were occurring between the first and second carcass ply from the tread area. It is more descriptive to call it between the first and second plies since this is generally where it occurred, rather than counting from the innerliner and saying it's between the eighth and ninth ply on carcass A or between the tenth and eleventh ply on carcass B, which would be quite variable.

Q: What size tire was related to the treads?

A: The tire is 26 inches in diameter and 66 inches wide.

Q: Did you have anything on the 40 x 14?

A: No, not yet. We have initiated testing on the 40 x 14 and the initial indication after the first phase of our testing shows that the rate of propagation is not as rapid as we see here.

Q: Do you have any intent to publish any of this data on the 40 x 14?

A: At this particular moment, no; but probably in the future, yes.

Q: The tires that were selected for this test program had natural anomalies. Did they have a previous service history or uniformity?

A: All the separations or anomalies in them were of a non man-made function. They were either developed in the tire during the dynamometer testing or they had occurred through a previous service life. The series of tires that we ran were both new and rebuilt tires so some had experienced a previous service life.

Q: You might mention they were all R-1 carcasses obtained from the Navy after a service tour except for the new ones, so there's only one service tour.

A: Yes, but the service tour that the tires see on aircraft can be highly variable even though they were R-1 levels.

Q: What was the age of the tires you tested?

A: They were of various ages. Some were at the time that this study was initiated, brand new, fresh out of the molds; others were up to approximately eight years old.

Q: Why is there a differing rate of separation with respect to the different rate of growth?

A: I would interpret it as being a higher stress load in the shoulder of the tires versus the center line. As indicated by the previous speaker, the increase in the tire pressure on the dynamometer to compensate for the deflection is overstressing the tire which would additionally be very critical in the shoulder area.

Q: Would that imply that if I started out initially with a 1/8" separation that they will all grow at the same rate?

A: I would not expect them to grow at the same rate. By the nature of the components that we're talking about, I would expect them to grow relatively similar for any one group, for instance, if they were all located in the shoulder of the tire.

Q: What is the correlation between the dynamometer tests and fleet usage?

A: I can't answer that question. I don't know if test data is large enough to indicate what variation in size growth that we will see. Since we're testing on the dynamometer versus testing out in the fleet, whatever data that we accumulate on the dynamometer is not necessarily translat-

able to what we can expect in the fleet. We have seen that some of the tires from fleet usage will not grow to such large dimensions as rapidly as they do on the dynamometer. But the advantages of using the dynamometer are, of course, it's a controlled environment. You can repeat the same test over and over again. In the Navy, each aircraft may fly five or six different flight profiles.

Q: Is there any relationship between the age of the tire and the speed of the failures?

A: No, none at all. Some of the new tires failed just as rapidly as the oldest tire did.

Q: I understand that you say that some of the tires were up to eight or ten years old?

A: Yes, some of the carcasses were.

Q: Some of the carcasses were still only R-1 positive. Were these tires stored as R-1's and what is the environment of the Navy warehouses?

A: The tires used in the experiment were retreaded less than a year before and had not entered the Navy supply. The Navy warehouse system is very extensive and the normal lag time within it can be very lengthy. For instance, I could go to a supply warehouse and pick out a brand new tire that is ten years old. The aircraft tires are supposed to be stored in a cool, dark location, away from hot pipes, fluorescent lights, and sunlight. With storage facilities from here to Alaska to the Philippines, including aircraft carriers, the storage conditions of the tires may not always be optimum.

IMPROVING QUALITY AND EFFICIENCY OF MILITARY TIRES FOR LOW LIFE CYCLE COSTING

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Buffalo, New York 14221

INTRODUCTION

The purpose of this symposium is to report the progress of the nondestructive tire testing technology which is a continuation of the reports presented during the last symposium in Akron, Ohio in January, 1976.

The emphasis on Nondestructive Testing (NDT) studies is placed on the development of technical and scientific means of accurately identifying potential tire casing failures, or progressive casing deterioration within the carcass composite. The reported studies demonstrate a satisfactory progress in advancing the NDT capabilities in predicting tire failures for the selection of reasonably strong casings for retreads.

Nondestructive Testing measurements can easily detect the mechanical degradation of tire casings. It cannot detect or predict the physical changes and loss of properties in rubber and adhesive bond components.

Although this phase of the NDT program has been satisfactorily progressing, the program does not analyze the degradation of rubber, the mechanism of tire failures, and the relationship between ply separations and failures. As a result, tire degradation continues to be a major problem, because of high tire prices, short service life, and the resultant waste of critical materials, when the whole tire is scrapped as soon as, or before the tread is worn out.

Corrosion is a universal problem and a costly one. New methods and products for reducing or preventing corrosion have been introduced for both metals and rubber. However, at the same time, as industry seeks to improve production, offer new products and increase efficiency, the problems of corrosion and degradation are expanded. Estimates indicate that the added costs for preservation of rubber at the manufacturers' level, exceed $500 million a year at the expense of the consumer, and the results are still unsatisfactory.

The corrosion problem of metals has been substantially diminished by alloying and anodizing methods. Alloying of metals through the use of chemical treatments changes their surface chemistry, and provides high strength at the surface and resistance to corrosion and oxidation. The same principle applies for the protection of rubber from oxidation due to ozone and general environmental conditions.

Treatment of vulcanized rubber for protection from ozone attack and deterioration is relatively a new technology and has been applied in the materials' development for aerospace use. A special patented chemical antidegradant called AGE-MASTER #1, was designed for this purpose and constitutes a break-through in rubber protection.

Studies in polymer surface chemistry and test data, have demonstrated the effectiveness of this new technology that makes ozone susceptible rubbers immune to oxidation and ozone attack.

The concept of surface treatment of rubber with AGE-MASTER #1 was evaluated for aerospace application and used in the development program for the U. S. Air Force, Air Cushion Landing System (ACLS), Fig. A. The system comprises a large, elongated, doughnut shaped inflatable trunk (15 x 24 ft.), made entirely of natural rubber and elastic nylon cord, which is attached to the underside of an aircraft in place of a conventional landing system. The composite material system was designed for high strength, variable elastic characteristics, elastic recovery after extreme deformations and resistance to fatigue and tear.

The environmental exposure problem was the most critical factor, because of the requirements for maintenance of elastic properties and mechanical integrity of the composite.

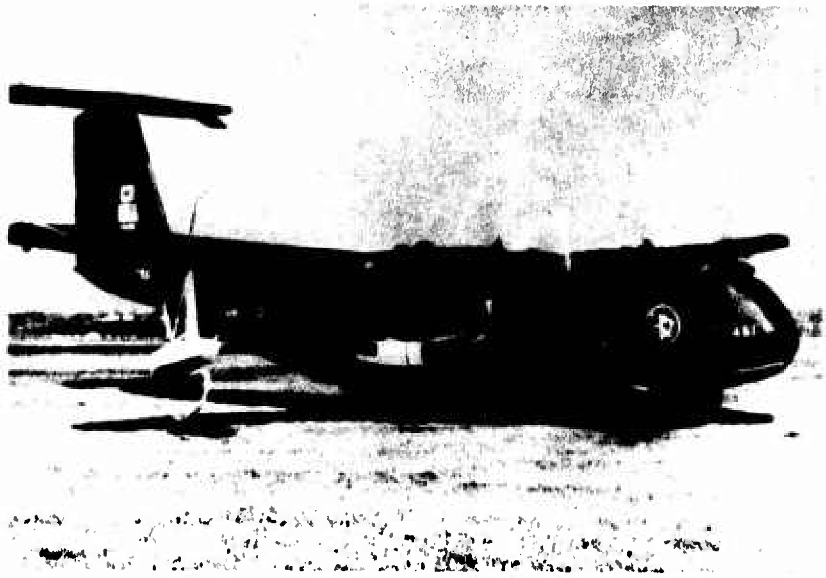
Treatment of rubber with AGE-MASTER #1 Rubber Protective Agent proved to offer an effective protection and was used for the treatment of all ACLS rubber components. The treated composites were successfully tested in taxi, take-off and landing tests on various terrains in Florida and in the Arctic Canada, and after three years of outdoor exposure showed no signs of degradation due to ozone attack. Untreated specimens of the composite which were exposed outdoors cracked and deteriorated within 30 days.

This technology and performance data should be of significant importance and interest for applications on military tires, because it provides the means to control and extend the service life of tires, maintain combat readiness, increase tire reliability, and increase recapability of tires for reduced costs. This novel approach makes possible the application Life Cycle Costing (LCC) methods for the procurement and maintenance of tires.

The following description of the basic mechanism of rubber and tire casing degradation develops the concept of

AIR CUSHION

LANDING SYSTEMS (ACLS)



An XC 8-A Aircraft was fitted with a new Air Cushion Landing System- a new development sponsored by the U. S. Air Force and Canadian Department of Industry and Commerce. The aircraft is able to take-off and land on a cushion of air. The Air Cushion System operates around a large rubber trunk, costing $500,000.

Unprotected samples taken from the trunks and tested showed cracking in 30 days. Thus, the useful life was very short. Those samples protected with AGE-MASTER NO. 1, did not crack or deteriorate after one year of outdoor exposure.

Trunks fitted to the aircraft and treated with AGE-MASTER No. 1, have lasted over four years without cracking or other signs of deterioration.

FIGURE A

tire protection, and gives examples of its practical utility in extending tire service life.

DEGRADATION OF RUBBER

The subject of rubber degradation and deterioration of tires is very extensive and technical. However, for better comprehension of the problem, and appreciation of the solution offered to diminish this problem, we are presenting only the highlights of the problem with factual results.

Natural and synthetic rubbers are particularly susceptible to atmospheric oxidation which causes polymer degradation, and loss of elastic properties and strength.

Oxidation by oxygen causes chemical and physical changes in rubber, and results in loss of tensile strength, resilience, elasticity and hardening. However, none of these are visually detectable. Precise measurements are required to detect the extent of such degradation and damage.

Ozone attack is another form of oxidation of rubber which causes rapid chemical and physical changes of the polymer structure, and the damage to rubber is readily visible. Ozone attacks the elastomer at the double bonds and causes cleavage of its polymer chains. This cleavage initially forms microscopic cracking on the surface, which in a few hours or days can become quite large. Cracking develops in a direction perpendicular to the direction of stress. *FIG. 1* shows typical ozone cracking of rubber. Ozone cracking can propagate deep down to the tire core reinforcement and attack the adhesive bond of rubber to fabric, *FIG. 2.*

Ozone attack on rubber also results in another serious oxidation of rubber by the release of singlet oxygen ($^1O_2$), an extremely reactive form of molecular oxyten. Singlet oxygen ($^1O_2$) can diffuse a significant distance through solid polymers and can react rapidly with their functional groups. It also attacks the adhesive bonds of rubber to rubber plies.

Tire casing deterioration is caused by the combined effects of rubber aging, atmospheric exposure (Ozone, oxygen, heat and UV light), dynamic mechanical stress, and flexural fatigue. The deterioration starts with incipient separations in the tire casing structure and microcracking on the surface of the rubber, which often leads to questionable tire dur-

TYPICAL EXAMPLES OF OZONE AND WEATHERING DAMAGE

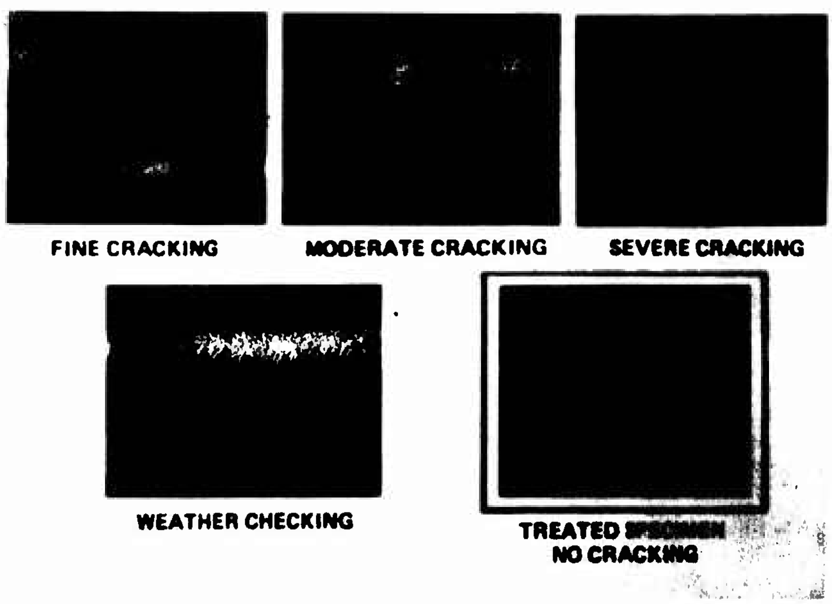


FIGURE 1

Typical examples of ozone and weathering damage. Natural rubber truck tire sidewall compound specimens showing different degrees of rubber deterioration caused by ozone, pollution, weathering and aging. Treated specimen shows excellent resistance to weathering and ozone attack.

EFFECT OF OZONE CRACKING ON TIRE DEGRADATION

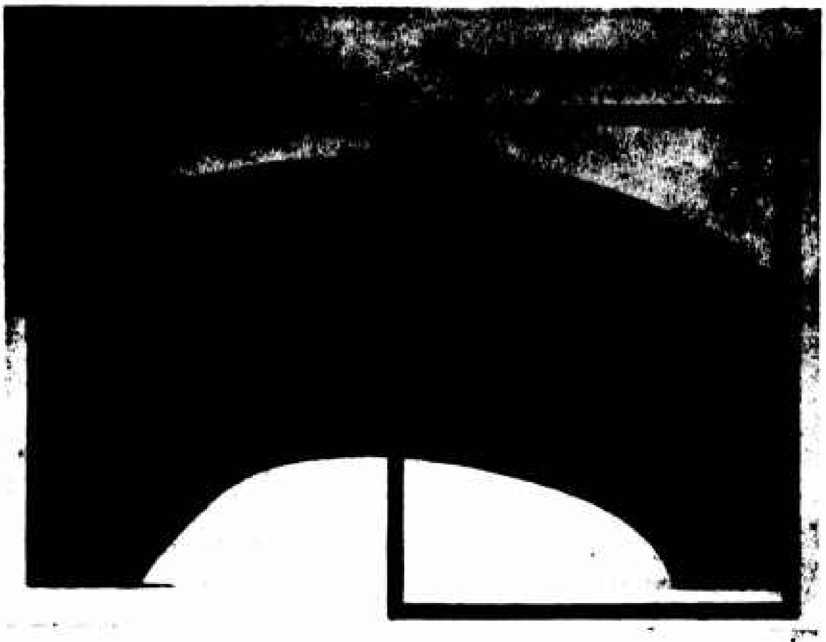


FIGURE 2

Side view of truck tire tread section showing depth of cracking. Treated groove with AGE-MASTER No. 1 shows no groove cracking. Untreated groove shows cracking extending into the fabric reinforcement (tire cord). This helps water and moisture get to the cord to start separation of tire plies and loss of tread on the road.

Tire section was exposed to 50 pphm Ozone (parts of ozone per hundred million parts of air) at 75°F, 36 hours exposure time. Fine cracking was observed on the untreated side in 4 hours, and propagated to very severe in 36 hours.

ability or premature failure. In severe cases, the degradation may cause rapid cracking of the sidewall and tread grooves, ply separations, sidewall flex breaks and reversion at the shoulder and tread areas.

Sidewall and tread groove cracking, which often reaches deep into the fabric reinforcement of a tire casing, can accelerate the problem of ply separations by the absorption of moisture or water through the capillaries of the cord filaments; significant amounts of moisture can be trapped in those areas, and develop in top-blows and separations when the heat build-up of the tire reaches to elevated temperatures.

Current industrial practice is to use various antidegradants and waxes in the rubber compound to promote the necessary resistance to oxidation and aging of rubber. However, from normal performance and laboratory tests, we can determine that there is a serious deficiency in their protective action, which results in premature failures and total replacement of tires.

THE NEED FOR EFFECTIVE PROTECTION OF TIRES

Aging of rubber is a complex phenomenon, and a major factor affecting tire life. Other factors are: Underinflation, overload, and speed. All these factors can be easily controlled and constitute part of tire maintenance programs in commercial fleets. Aging and oxidation are either neglected because the consumer cannot find an effective product for maintenance, or are totally ignored by the consumer because the information on this subject is limited to the rubber chemist, only.

Military tires which are expected to last longer than commercial tires (5-6 years), because of low service mileage, require an effective protection for preservation. Such a protection will make possible the retention of carcass strength integrity for multiple recaps, and the procurement of regular off-the-shelf commercial tires as needed.

Procurement of off-the-shelf commercial tires for military use offers economic advantages, and supplies could be

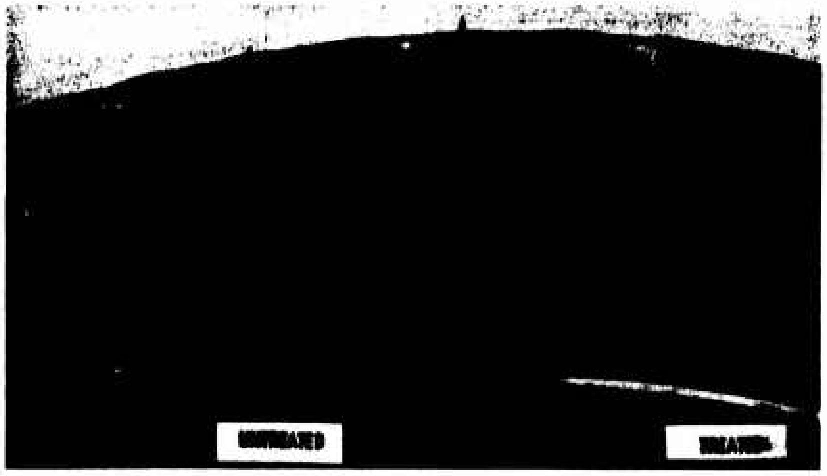


FIGURE 3

10.00 – 20 TRUCK TIRE

Exposed for 6 months outdoors in Los Angeles. Unprotected section developed cracking during the first month of exposure. Protected with AGE-MASTER # 1 section showed no cracking at the end of the test period (6 months).

The test shows the tremendous difference in ozone and weather resistance brought about by this chemical treatment using AGE-MASTER #1.

TRUCK TIRES

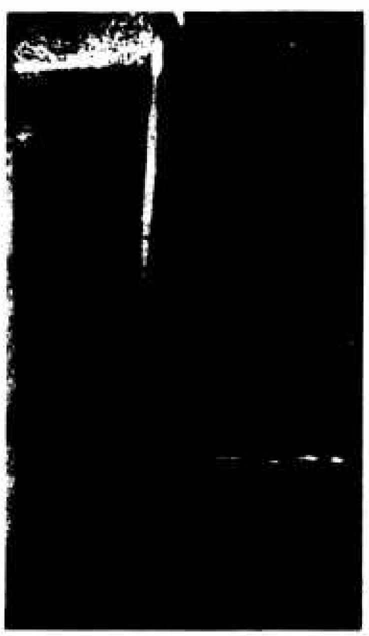


FIGURE 4

This truck tire sidewall section represents a premium truck tire available in the market. The untreated section is severely cracked and deteriorated. The section treated with AGE-MASTER No. 1 did not show any degradation or cracking and retained its ozone, at 75°F.

readily available without the need of special orders under MIL-specifications.

The need for rubber protection is illustrated by the following tests performed on commercial truck tires, and rubber compounds. *FIG. 3* shows a truck tire with ½ of the sidewall and tread treated for protection and the other ½ untreated. It was inflated to rated pressure and was exposed outdoors in Los Angeles for 6 months. The untreated control section of the sidewall and tread grooves showed severe cracking which propagated deep into the fabric region. The treated section showed no signs of any degradation.

FIG. 4 shows a specimen of natural rubber truck tire sidewall compound with ½ of its surface protected and the other ½ unprotected. The sample was exposed to ozone at constant load simulating conditions of tires on military motor vehicles in storage. Again, the unprotected section showed severe deterioration due to ozone attack.

Samples of Natural/Diene rubber blend compounds used for tires were tested outdoors in Buffalo, NY., and at Riverside, CA., to determine their environmental resistance against identical specimens treated with AGE-MASTER #1 rubber protective agent. Table 1 briefly shows the test results. The samples represent high quality rubber compounds with various antioxidant and antiozonant materials in the rubber matrix. In all cases, the rubber treated with AGE-MASTER #1 retained all its elastic properties without signs of any deterioration.

In addition to the molecular break-down which causes cracking of rubber, oxidation changes the original proper-

TABLE 1

OUTDOOR WEATHERING TESTS

A. PERFORMED AT RIVERSIDE, CA. FROM AUGUST TO OCTOBER 1977
3 MONTHS TEST. ASTM D-518 B LOOP TEST.

RUBBER COMPOUNDS	TREATED WITH AGE-MASTER #1	RIVERSIDE, CA. RESULTS AFTER 3 MONTHS EXPOSURE
126 – Natural/Diene Rubber	No	Very Severe Cracking
126 – Natural/Diene Rubber	Yes	Crack Free
127 – Natural/Diene Rubber	No	Very Severe Cracking
127 – Natural/Diene Rubber	Yes	Crack Free

B. PERFORMED AT BUFFALO, NY. FROM JANUARY 1975 TO JANUARY 1976
ONE YEAR TEST: ASTM D-518 B LOOP TEST.

RUBBER COMPOUNDS	TREATED WITH AGE-MASTER #1	BUFFALO, NY. RESULTS AFTER ONE YEAR
Natural Diene/Rubber	No	Very Severe Cracking
Natural/Diene Rubber	Yes	Crack Free

ties of rubber and affects the adhesive bond of tire components. thus, as aging of a tire increases, the adhesion of tread to carcass, rubber to cord reinforcement, and sidewall junctures decreases. This reduction in strength is the combined effect of oxidation flex fatigue. *FIG. 5* illustrates the effect of aging on the strength of rubber and adhesion to carcass. This degradation results in tread and ply separations, top blows, voids and general strength reduction of the carcass composite.

Oxidation also results in high heat build-up due to the loss of hysteresis and resilience of rubber. Heat has an adverse effect on the strength of rubber and adhesive bonds. As temperature increases, strength decreases in a linear fashion as shown in *FIG. 6*. A tire running at 210°F, is expected to be operating at 50% of the initial tensile strength of the rubber, 40% at 225°F and 30% at 250°F. This reduction in strength is accentuated by the oxidation process and may cause incipient separations, reversion and premature failure.

PREVENTIVE ACTION

The preceding discussion identifies the need for tire protection, and introduces a product to accomplish this task.

This new development for preservation of tires offers a surface chemical treatment which effectively shields and prevents oxidation and ozone attack of rubber. As shown in *FIG. 7*, the chemical treatment is accomplished by externally applying a specially designed chemical agent. The material penetrates deep into the rubber, and provides

EFFECT OF AGING IN RUBBER STRENGTH AND ADHESION OF TREAD TO CARCASS

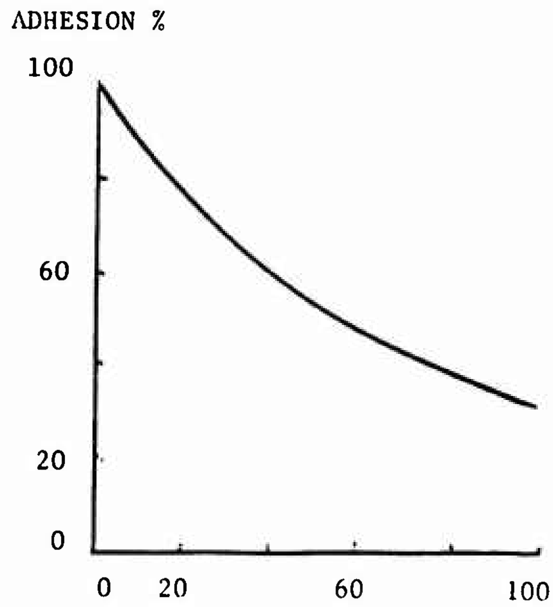


FIGURE 5

Reduction in tire compound properties due to aging and fatigue of rubber.

a high concentration of an effective antioxidant at the surface and subsurface of the rubber where ozone attack and oxidation take place. It provides an intramolecular stabilization sysem and its activity is not impaired by flexing or scuffing during the service of a tire.

External treatment for the protection of tire integrity for more retreads is an essential part of tire maintenance. The advantages of tire protection are the following:

- Increase tire life and mileage performance
- Increase carcass life for more retreads
- Cooler running temperatures
- Reduced expensive road calls and labor
- Reduced cost per mile
- Reduced Life Cycle Cost

The protective agent available for the external treatment of rubber is AGE-MASTER #1, and it is produced by CHEM-PRO MFG. CO., Inc. of Buffalo, New York, under U. S. and Foreign patents.

SUMMARY

It has been demonstrated that the present problem of tire carcass degradation can be substantially diminished by chemical treating the surface of the rubber. This approach will contribute to sound tire carcasses for retreading, and will make possible the increase of the present number (10-15%) of re-built tires to the 70% level, as required by the Army.

The discussion and presentation of facts is to provide the Army with information on advanced technology in this field, which is available for immediate application.

For this reason, we are inviting you to explore with us this novel approach in applications concerning your particular studies in improving tire durability.

We also recommend the incorporation of this approach on future tire tests of military or aircraft tires.

As a final comment, I want to emphasize that protection of rubber contributes, substantially, to the preservation of energy related materials, and particularly petrochemicals used in rubber products.

EFFECT OF HEAT IN RUBBER STRENGTH

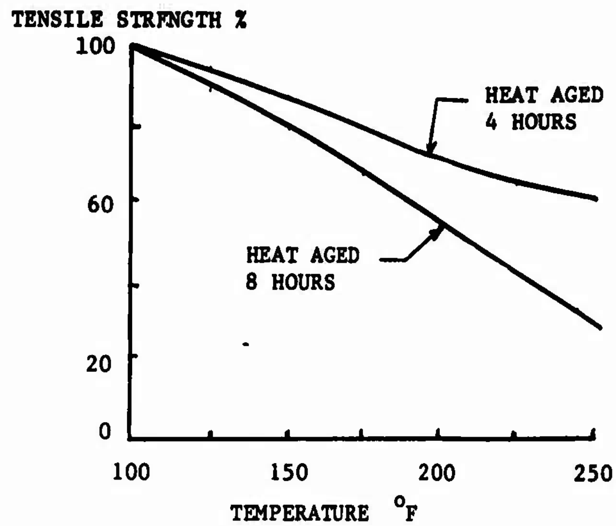


FIGURE 6

Reduction in tensile strength of tire compounds with increase in temperature.

AGE-MASTER #1 EXTERNAL TREATMENT

HOW IT WORKS

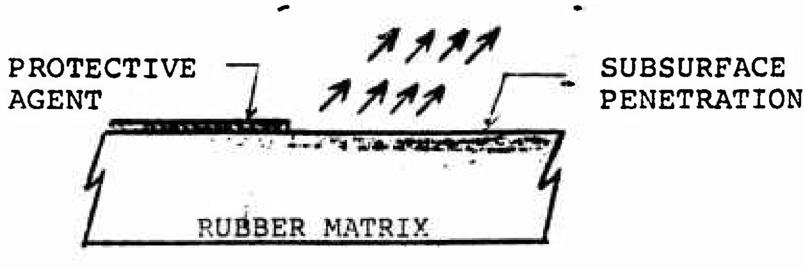


FIGURE 7

Externally applied to vulcanized rubber, AGE-MASTER #1 penetrates deep into the rubber, and provides an effective intra-molecular protective system against oxidation and ozone attack.

NATURAL RUBBER TRUCK TIRE SIDEWALL

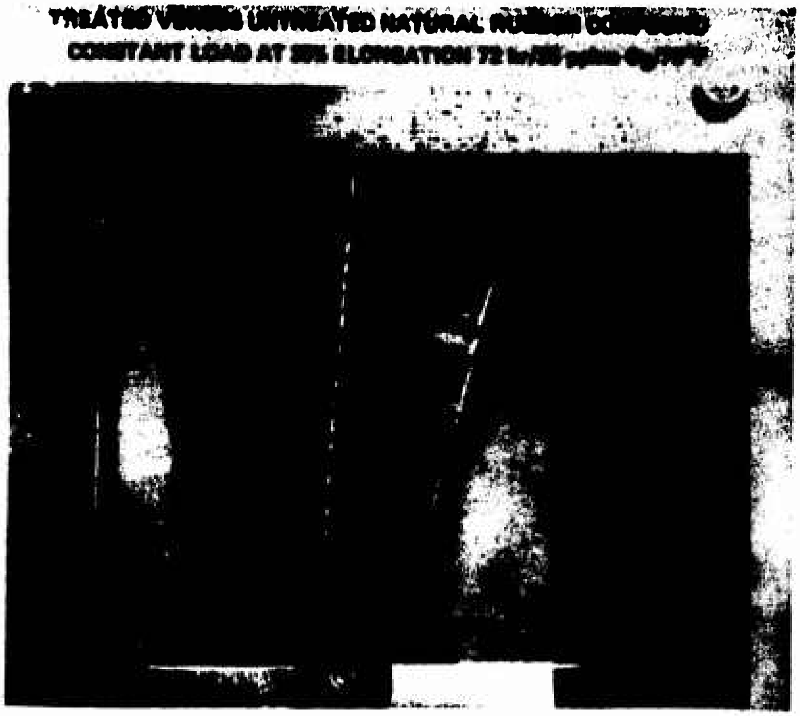


FIGURE 8

Natural rubber truck tire sidewall sample exposed to 35 pphm Ozone (ASTM D-1149) for 72 hours in an Ozone Chamber at 75°F. Shown here stretched to 25% elongation under constant load, cracking destroyed the untreated side, while the side treated with AGE-MASTER #1 did not crack at all.

The unprotected rubber lost all its elastic properties and strength, and it is a "dead" rubber. In comparison, the protected rubber is like new, alive, and retained all its elastic properties and strength.

QUESTIONS AND ANSWERS

Q: What is the ozone concentration that we were talking about under accelerated testing?
A: Most of the accelerated testing was conducted under ozone concentrations of 50-55 pphm (parts of ozone per hundred million parts of air). Other tests were also conducted under 100 pphm ozone, in conformance with specifications requiring extreme ozone resistance.
Q: Is it in an ozone chamber?
A: In an ozone chamber under controlled conditions for ozone concentration and temperature at 75°F.
Q: Did the time of surface treatment and concentration make any difference in the performance of the product?
A: Yes, the best time to apply the treatment is as soon as the tire is cured, preferably at the final finish stage. If this is not possible, we recommend treatment as soon as possible while the tires are relatively new, because oxidation and ozone attack take place immediately after the tire is out of the curing press. Early treatment will render the best protection. Concentration is important.

Another advantage of this system is that you can use it during the service of the tire as a preventive maintenance program. Present tire maintenance programs require proper inflation, tire rotation and tire balancing. They do not include protective measures to prevent deterioration of rubber (side-walls, and tread grooves), due to weathering and environmental exposure. Protective coatings are used for the protection of houses and industrial installations from deterioration and corrosion. Surface treatment of metals is an advanced technology used to make metals stronger, and abrasion and corrosion resistant. But, for rubber and tires, we seem to be doing nothing for their protection. If we are very serious about protection of tires, there is one way that we can do it, and this is by using this novel approach of surface treatment of rubber. Treated radial tire sections tested under flex conditions in an ozone chamber showed no cracking at the flex area after 15 days of exposure. The same untreated sections showed flex cracking within 2 days under the same conditions (50 pphm ozone).
Q: How do you apply this?

A: Apply AGE-MASTER #1 using a brush, roller, airless spraying or dipping. Application can be made at any time before use or during service. New tires, not treated by the manufacturer, can be treated by the user. Application is very simple. Manufacturers can treat tires before or after the final finish process. Treatment is completely dry in 15 minutes.

Q: Does your material actually migrate into the rubber to form a barrier around the double bond?

A: Yes. The material as applied, soaks into the rubber, and it is designed to be absorbed and deposited into the polymer structure. It provides an intramolecular protective system that cannot be removed by flexing or scuffing. The material does not react with the polymer structure or double bonds, but remains there to react with the elements (ozone, or singlet oxygen) and arrest them before they will attack the double bonds of the rubber. This is the function. The material penetrates into the rubber 1 to 3 mils. Penetration and absorption depends of course, on the type of rubber and compound formulation. Type of fillers, plasticizers, and porosity of the vulcanizates are factors controlling the rate of absorption.

Q: Have you had any interest shown in the deicer boot application?

A: Yes, Sir.

Q: Who treats the deicer? The O.E. manufacturer?

A: No. Treatment of deicer boots is done by airlines and the owners of private airplanes. They found out that AGE-MASTER #1 is very efficient in protecting the deicer boots, even though they are made of Neoprene, which is considered to be an ozone resistant elastomer.

Q: Why doesn't B. F. Goodrich actually advertise this?

A: I don't know, Sir. We are in contact with B. F. Goodrich and of course they know about our material very well. They have tested it, analized it and they know its function and performance. So did Goodyear and major tire and rubber manufacturers all over the world.

Q: Given that the tire manufacturer is not prepared to do this immediately, how can the manufacturer of the tire do it within a few weeks? Can it be applied by the user after it's been in storage for two or three months before he gets it, and what is significant about it?

A: If a tire manufacturer is not prepared immediately to do the treatment in a mass production assembly line, he could do the treatment in a bay area, and as soon as the area is available without any special equipment. The treatment can be applied by the user after the purchase of tires. It is recommended that tires be treated as soon as they are manufactured, because oxidation of rubber starts immediately after cure. The user should continue application as a maintenance procedure to protect new surface exposed, as a result of sidewall scuffing and wear.

The significant factor between treating a tire after manufacturing and a new tire that was stored in a warehouse for a period of time, is that the tire from the warehouse has been already oxidized and already attacked by ozone. Microcracking which may develop as a result of this exposure, is the initiation of rubber degradation. Treatment of this tire will prevent propagation of cracking, and reduce the possibility of early failure. Military tires in storage at various depots or in transit may severely deteriorate before any use. Early treatment of tires, therefore, for protection and preservation is a significant economic factor.

Q: Is there a time factor involved for how long this coating will protect?

A: From laboratory test data, and actual field service performance of treated rubber products, we can state that the treated products showed an outstanding resistance to deterioration, with a service life longer than their untreated counterparts. The Air Cushion Landing System trunk, for example, treated with AGE-MASTER #1 showed no deterioration due to ozone for as long as 4½ years of outdoor service and exposure under constant strain of at lease 25% (trunk's relaxed mode). Similar untreated trunk sections tested under the same outdoor conditions deteriorated in 30 days exposure.

When the surface is severely abraded and the treatment surface is removed, simple local application for the treatment of the new exposed surface is sufficient to provide the required protection.

The protective agent remains at high concentration on the surface and sub-surface where ozone attack and oxidation take place. This material gradually reacts with the ozone and forms a protective layer of an ozonite compound. This ozonite forms a barrier, so that ozone cannot attack the rubber, and the singlet oxygen does not penetrate deep into the rubber to cause damage to the tire casing. This is the protective system.

Our technology and studies confirm with the findings of the National Research Council of Canada. They have done an extensive study on the degradation of rubber, and they defined the factors which I presented in a very brief way. Their findings coincide with our findings and this is why we're trying to inform you on this development.

We have the material that works and does the job of protection and offers a solution to the problem of rubber deterioration.

To many of you who are not involved in rubber technology, the complexity of the problem may not be very obvious. However, this subject is very complex and extensive. Specifically on this subject, the State University of New York is offering a five day symposium next month, and a seminar on the rubber degradation and recent advances on the stabilization technology of polymers. You can see how extensive this subject is.

BEAD INSPECTION TECHNIQUES BY BENDING RIGIDITY AND CONTOUR MEASUREMENTS

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INTRODUCTION

For many years, there have been only two practical bead-inspection techniques available to the pneumatic tire industry. The first of these is hand and visual inspection, which has been developed to a relatively high degree of skill by trained tire inspectors. Nevertheless, in many cases they are not able to find internal defects, particularly relatively small ones, and for that reason many tire companies have relied on a second inspection, that of x-ray or fluoroscopic examination of tires, to determine internal characteristics of tire beads. One of the purposes of this present paper is to discuss the development of methods for inspecting tire beads which do not rely on these two conventional procedures.

The ever growing use of radial tires leads to the suspicion that because of their particular construction, bead loads will generally be higher with radial tires than with conventional tires. While unusual incidences of bead failure have not been reported, nevertheless, tire beads do perform in a cyclic stress, or fatigue limited, environment. Increased retreading of radial tires is apt to result in the use of tire beads over two or more life cycles under cyclic stress conditions somewhat greater than would be the case with bias ply tires. For this reason, mechanized or quantitative bead-inspection techniques would be of considerable value to the retreading industry.

Our previous work on the development of inspection techniques for passenger car tire beads was in two areas. First, we examined the general stress state in a tire bead on an analytical basis. Information obtained from this analysis was used to pinpoint the most likely areas of tire bead failure.

A partial verification of this analysis was obtained by experimentally measuring bead wire forces at different locations throughout the bead bundle. These measurements showed a tendency for an effective stress concentration to exist in the first layer of bead wires, as predicted by analysis.

The second major effort of this program was a careful study of several possible techniques for determining flaws in worn tire beads. The techniques studied included use of x-rays, electromagnetic eddy current detectors, and mechanical devices. It was concluded that a mechanical head stiffness monitoring system was the most practical means of identifying apparent flaws in tire beads. This device consisted of a modified belt-driven tire inspection machine instrumented with a displacement indicator which showed positions of unusual change in the bead contour and stiffness. These positions were often locations of severe bead damage including such surface flaws as cuts or chunks, as well as kinks, bends, and broken wires in the bead bundle.

Upon completion of these two studies, described in [1], it was decided that further modification and automation of the bead stiffness monitoring system was well worthwhile. Such modifications and use of the resulting apparatus are the major subjects described in this paper.

BEAD-INSPECTION ADAPTER – APPARATUS AND TEST RESULTS

From the results of previous work, [1], it was decided that the most practicable and usable device for detecting flaws in tire beads was a mechanical one in which variations in bead stiffness and contour could be continuously monitored around the circumference of the bead. In order to accomplish this in a practicable way, a bead-inspection adapter (BIA) was designed which could be attached to the spreader arm of an automatic tire inspection machine. This device does not alter the basic design and operation of the inspection machine. A photograph of such a machine with a BIA attached is shown in Figure 1.

The basic feature of the BIA is a displacement transducer which is spring loaded against the spreader arm of the tire inspection machine. Tire beads are inspected as follows: A tire is placed in the machine and the spreader arms are positioned so that their rollers are in contact with the inside edge of the bead. The arms are then spread by means of a pneumatic cylinder and mechanical linkage assembly. Attached to the arm is a displacement transducer which converts the displacement of the spreader arm into an electrical signal. A photograph of this BIA is shown in Figure 2. As the tire is rotated by the motor-driven cylindrical drums of the tire inspection machine, a continuous record of the displacement is displayed on an x-y plotter. One axis of the recorded graph represents the relative displacement of the transducer, while the other represents the position around the circumference of the tire bead.

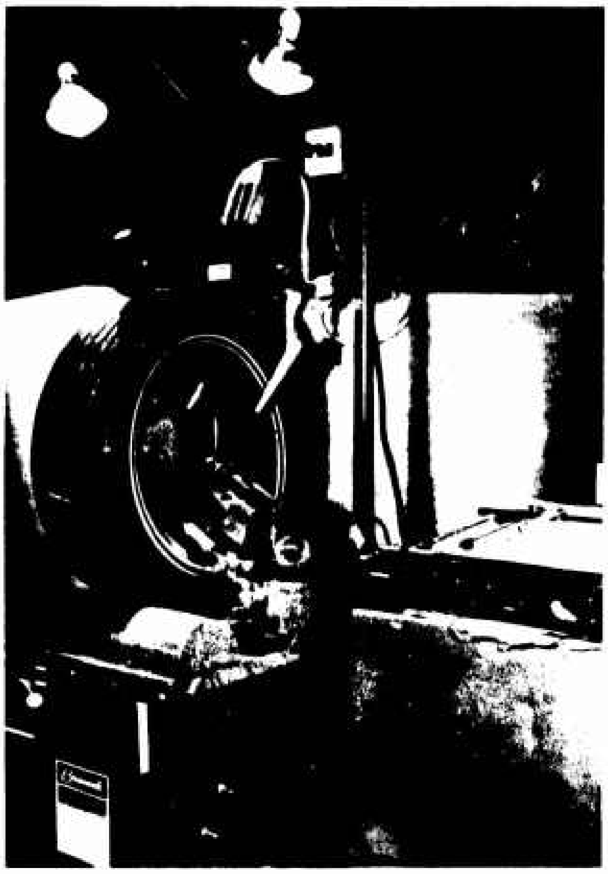

FIGURE 1

AN AUTOMATIC TIRE INSPECTION MACHINE WITH A BEAD-INSPECTION ADAPTER (BIA) ATTACHED TO THE SPREADER ARM

The BIA operates by displaying an electrical signal indicating deflection of the bead spreaders. In the vicinity of some bead anomaly, such as a bead kink, a bead cut, a bead chunk, a badly bent bead, or a broken bead, the bead spreaders will deflect abruptly causing a rather sharp signal to be produced in the electrical output of the system. This abrupt change is either due to an unusual contour change or bending stiffness. This unusual change, as compared with the signal from the rest of the head, can be observed and used to identify the presence of an anomaly.

It is interesting to note that each bead exhibits its own individual, reproducible signature from the output of the BIA. With some training, one can learn to "read" these signatures and identify not only the location but, in many cases, the nature of the flaw.

Having developed the BIA and installed it in an automatic tire inspector, a test and development program was begun to evaluate its usefulness. It was used to examine the beads of 70 tires. These tires were collected by a tire retread shop. They were selected by a reputable shop manager who sorted the tires on the basis of their bead condition. He purposely included many tires with known bead flaws, as well as some with good beads.

The major purpose of these tests was to establish a criterion for detecting flaws in the bead region of tires. These could be flaws such as cuts, chunks, bends, kinks and breaks.

As the 70 tires were tested, it became obvious that with a little training one could learn to "read" the bead signatures recorded on the x-y plotter and identify the presence of bead flaws. In addition, it became possible to recognize certain characteristics of the signature which often indicated the type of flaw present. A summary of these findings is illustrated in Figures 3 through 8.

In Figure 3, the photograph shows a typical bead with surface cuts. Above the photograph is a copy of the actual signature recorded for this bead on the x-y plotter. The shape of this sudden drop in signal is characteristic of serious bead surface cuts.

The photograph in Figure 4 illustrates a bead that was badly chunked to the fabric of the bead bundle. A copy of the signature for this bead is shown above the photograph and again illustrates a characteristic signal that typifies most chunked beads.

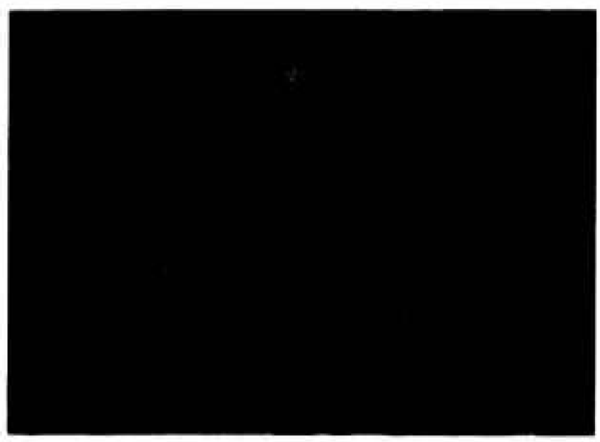

FIGURE 2

BIA USED FOR DETECTING SUSPECTED FLAWS IN TIRE BEADS

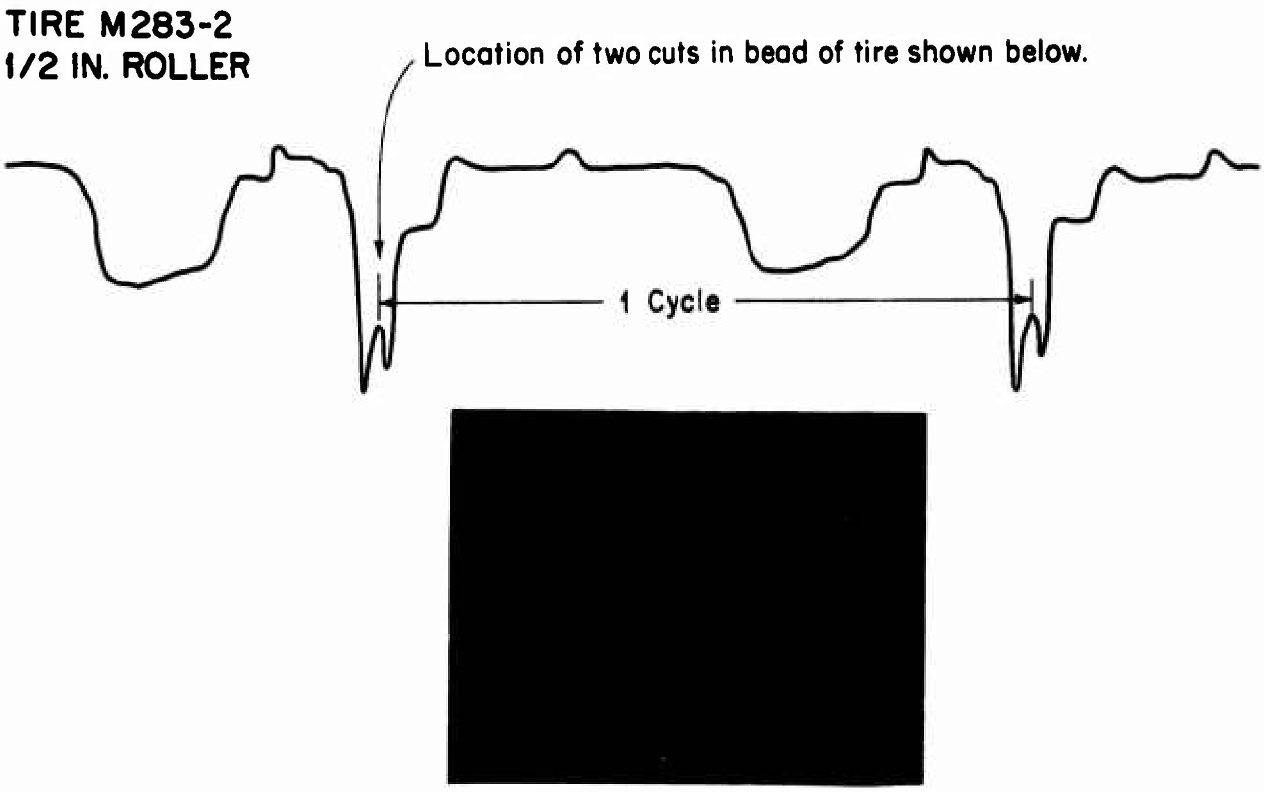

FIGURE 3. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL BEAD WITH SURFACE CUTS

Figure 5 illustrates a typical signal recorded from a tire bead with a severe bend. This type of flaw usually produces a large signal change. The photograph beneath the signature shows that severity of this bend. Even though this illustration seems to indicate that it is relatively easy to recognize a bent bead, it has proved to be the most difficult flaw to appraise consistently. All bent beads show a decrease in signal to some degree. However, it has proved difficult to judge the severity of a bead bend strictly from the magnitude of the signal change. To date, we have tended to be more critical of bead bends than have visual inspectors.

Figure 6 shows a dissected portion of a tire bead that was rejected because of a severe kink. This flaw was easily detected as the copy of the signature shows.

The photograph in Figure 7 illustrates the dissected portion of a bead bundle with several broken wires. As seen from the recorded signature, this flaw was also easily detected.

At the conclusion of this test program, the retread shop manager's written assessment of the tire beads was compared with the decisions made on the basis of records

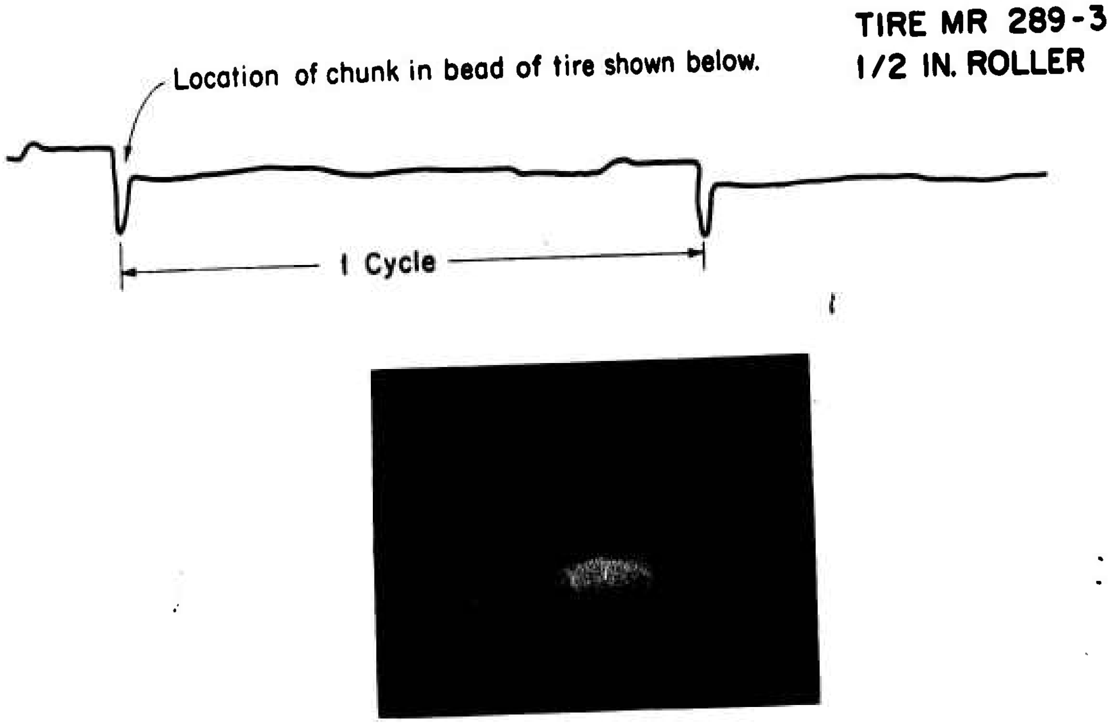

FIGURE 4. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL CHUNKED BEAD

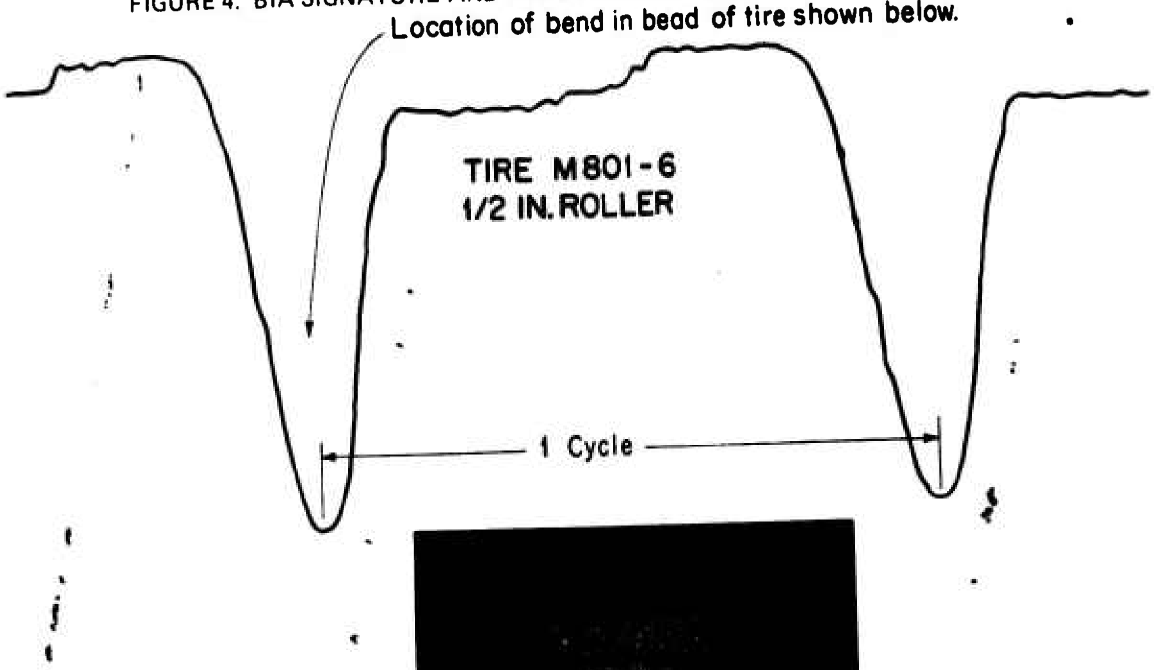

FIGURE 5. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL DISSECTED BENT BEAD

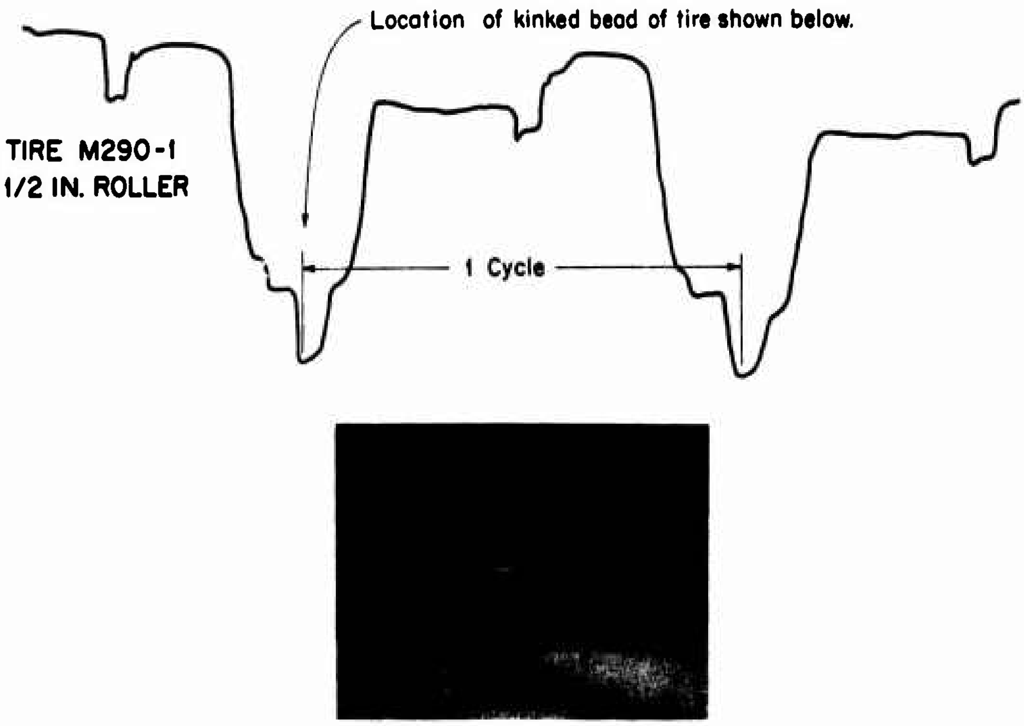

FIGURE 6. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL DISSECTED KINKED BEAD

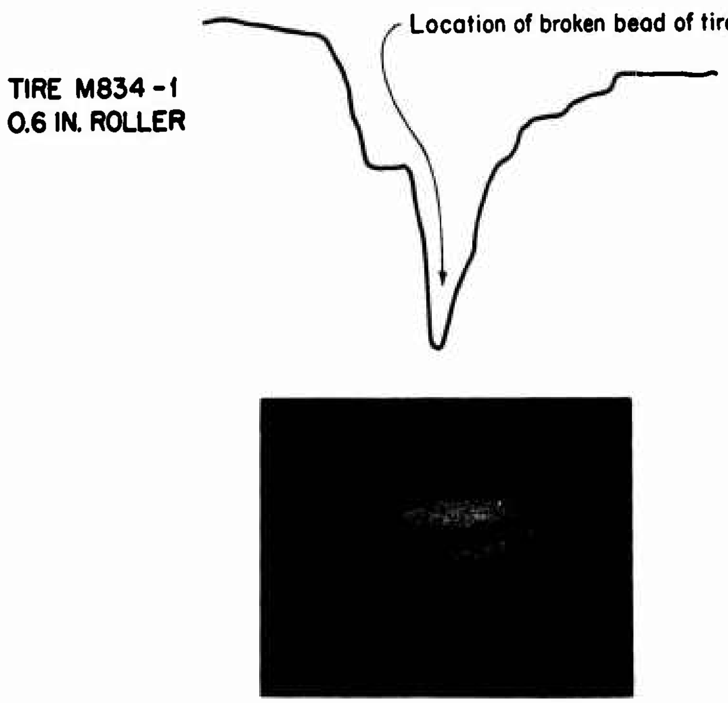

FIGURE 7. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL BEAD DISSECTED TO SHOW A BROKEN BEAD

from the BIA. A correlation between the acceptable and unacceptable tire beads as determined by the shop manager and the BIA is shown in Table I.

As seen from this table, the operator of the BIA rejected 56 of the 57 tires rejected by the manager of the retread shop. The BIA also accepted four of the 13 tires accepted by the shop manager. It should be noted that of the nine tires rejected by the BIA operator but accepted by the visual inspector, six involved tires with bent beads. In each of these six cases, the shop manager did not feel that the nature of the bend warranted rating the tire unacceptable. However, in the judgment of the BIA operator, each of these bends produced a recorded signature such that it was deemed appropriate to rate the tire unacceptable.

Of the 70 tires tested, there was only one that was rejected by the shop manager but accepted by the BIA operator. In this one case the BIA failed to indicate the presence of a cut in the bead rubber that had penetrated to the wire within the bead bundle. This cut was also "against the grain," meaning that the cut was such that the rubber was pressed back into the cut region as the roller passed over the damaged area.

The results of these preliminary tests indicated that the BIA could be successfully used to discriminate between tire beads with no flaws and those with such flaws as cuts, chunks, bends, kinks, and broken wires.

Although the major purpose of this part of the test program was to develop criteria for the rejection of tires with bead flaws, another important conclusion was drawn from these tests. It became obvious that one could learn to "read" the tire's recorded signature and from this determine the presence or absence of bead flaws. However, the magnitude of the output signal was not the only factor in determining whether or not a bead was acceptable. Instead, it was necessary to observe sudden as well as large signal changes. One way of doing this is to graphically display the signal on an x-y plotter and then interpret the record. This was the method used in the data discussed in the remainder of this paper.

A final test program was set up to examine 1000 tire beads with the BIA for the purpose of determining the reliability of this device as a means of detecting flaws in the bead region of tires. This program was divided into two parts. In the first part, 140 tires (280 beads) were selected by an experienced, professional tire inspector. Again, these tires were carefully chosen to include a wide variety of bead flaws, as well as some good beads.

These 280 beads were each examined with the BIA and then inspected visually by the inspector. A summary of the correlation between the BIA and the human inspector is shown in Table II. From this table, it is seen that in nearly 85% of the tests, the two results were in total agreement. Another 7% of the cases found the BIA operator rejecting a bead which had been approved by the visual inspector. Most of these disagreements involved bent beads. The remaining 9% of the cases were those in which the visual inspector rejected the bead but the BIA operator accepted it. Most of these cases involved beads that had been damaged on the outside surface of the bead where the roller of the inspection machine does not make contact, but where the flaws are easily seen.

From the results of this 140 tire sample, it is concluded that the tire inspection machine with an attached BIA is capable of identifying beads with unacceptable flaws. However, it should be remembered that this was not a typical sample of tire beads found in the field. It was heavily biased toward beads with flaws – 57%. In the actual service, the fraction of unacceptable tire beads is much smaller.

The second part of this test program involved using the inspection machine in a retread shop to examine 720 more tire beads. These tires were randomly selected from the large inventory collected by the retread shop. Once again, these beads were examined independently by a human inspector and by the BIA operator. A summary of the cor-

TABLE I. – SUMMARY OF RESULTS OF VISUAL AND BIA INSPECTION TECHNIQUES – 70 TIRES OF ORIGINAL TESTS

Human Inspector's Assessment of Bead Quality	BIA Operator's Assessment of Bead Quality	Number of Tires
Not acceptable	Not acceptable	56 (80%)
Acceptable	Acceptable	4 (6%)
Acceptable	Not acceptable	9 (13%)
Not acceptable	Acceptable	1 (1%)

relation between the two inspection techniques is shown in Table III. In this summary, it is seen that in nearly 93% of the cases, the BIA operator agreed with the human inspector. Of the remaining 7%, approximately one-half were rejected by the BIA operator but accepted by the human inspector. Of these disagreements, approximately 75% involved bent heads. In the remaining cases, the human inspector rejected the bead and the BIA operator accepted it. It was found that nearly half of these disagreements involved damages on the "flat" or outside of the bead area. Most of the remaining discrepancies involved beads with cuts "against the grain" or ones with long, shallow chunks. It is also noted that the total percentage of unacceptable beads in this sample was approximately 25%, which was much less than the 57% found in the previous sample.

Several other important observations can be made from data collected in this program. For instance, as it became obvious that there was a relatively high percentage of tires with bead anomalies (25%), a complete listing was made of tire bead flaws. A tabulation of these is shown in Table IV. Here it is seen that nearly all flaws are as-

TABLE II. – SUMMARY OF RESULTS OF VISUAL AND BIA INSPECTION TECHNIQUES – 140 TIRES (280 BEADS) – PHASE I – 1000 BEADS TEST PROGRAM

Human Inspector's Assessment of Bead Quality	BIA Operator's Assessment of Bead Quality	Number of Beads
Not acceptable	Not acceptable	135 (48.2%)
Acceptable	Acceptable	100 (35.7%)
Acceptable	Not acceptable	20 (7.1%)
Not acceptable	Acceptable	25 (8.9%)

TABLE III. – SUMMARY OF RESULTS OF VISUAL AND BIA INSPECTION TECHNIQUES – 360 TIRES (720 BEADS) – PHASE II – 1000 BEADS TEST PROGRAM

Human Inspector's Assessment of Bead Quality	BIA Operator's Assessment of Bead Quality	Number of Beads
Not acceptable	Not acceptable	139 (19.3%)
Acceptable	Acceptable	527 (73.2%)
Acceptable	Not acceptable	28 (3.9%)
Not acceptable	Acceptable	26 (3.6%)

TABLE IV. – FLAWS DETECTED BY VISUAL INSPECTION – 383 DAMAGED BEADS

Percentage of flaws contributed by bead surface cuts	17.3%
Percentage of flaws contributed by bead surface chunks	60.8%
Percentage of flaws contributed by surface flaws on "flat" of the bead or outside	9.1%
Percentage of flaws contributed by kinked beads	3.1%
Percentage of flaws contributed by severe bead bends	9.4%
Percentage of flaws contributed by broken bead wires	0.3%

sociated with damage occurring during the mounting or dismounting of tires. Although this program provides no remedy for such occurrences, it does provide clear evidence that there is a real need for improving mounting and dismounting techniques.

During this test program, a total of 29 beads with suspected flaws were examined further by dissecting the suspected area. Observations of these beads, in most cases, verified that the suspected flaws were indeed present. However, in a few cases no real flaws were found.

The results of the tests described above attest to the fact that it is feasible to design an adapter for a commercial inspection machine that can detect the presence of common bead flaws. The high percentage of agreement with visual and tactile techniques indicates that this inspection system can be reliable.

ACKNOWLEDGMENTS

The authors would like to acknowledge the generous assistance of the Firestone Tire and Rubber Company in cooperating with this study, and in particular Mr. Dale Maurer of the Firestone Retread Shop, Lansing, Michigan, who contributed generously of his time and knowledge in the retread area.

We would also like to acknowledge the cooperation and assistance of the Brannick Manufacturing Company, Fargo, North Dakota, who provided equipment which was modified under this program.

We would also like to acknowledge the technical assistance of Mr. Stephen Bobo, DOT/TSC, and for the advice and counsel of Mr. Manuel Lorenco, technical monitor for this program, both of the United States Department of Transportation.

This work was funded by the United States Department of Transportation, National Highway Traffic Safety Administration, Washington, D. C.

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NEW APPROACH TO NON DESTRUCTIVE ENDURANCE TESTING OF TIRES

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In general, tires are tested for endurance performance by either outdoor or indoor test procedures.

The outdoor test procedure determines the endurance performance of the tire by driving the tire continuously at specified loads and speed conditions on a test route to represent the extremes of customer usage.

The indoor test procedure determines the endurance performance performance of the tire by running the tires at specified loads and speed conditions on a smooth steel flywheel.

The majority of tire endurance tests are performed indoors. The indoor tests, which are generally run under far more severe conditions than those encountered on the road, provide an indication of the tire's durability in a fraction of the time which would be needed for equivalent outdoor tests. Department of Transportation (D.O.T.) standards specify test conditions and tolerance levels with respect to load, inflation pressure, speed, and ambient temperature.

This paper addresses the problems encountered by testing machines to meet these requirements and presents a solution to one particular problem, namely the regulation of the load to which the tire is subjected during the endurance test cycle.

Although not originally intended, the solution to the load regulation yielded another important feature which enables detection of the onset of tire failure. This feature provides the means to truncate the endurance test before massive destruction of the tire occurs, thus enabling the tire engineer to analyze the cause of failure in statu nascendi. Efforts to detect incipient failures using infrared and ultrasonic methods have been described in the literature (1, 2, 3). However, poor reliability of detection and the necessity for costly and sophisticated instrumentation to achieve detection curtailed wide spread use of these methods.

The problem of load regulation has plagued the tire industry since the introduction of closed loop hydraulic systems (Figure 1), replacing older type machines which used weights for loading purposes. (Figure 2)

The reason for introducing loading methods other than dead weight was obvious. Dead weight systems have inherent disadvantages. They are bulky, require supervision and cannot be programmed to perform automatic load changes. The approach to the solution of this problem must have looked simple; replace the dead-weight loading part of the tire endurance test machine with an automatic loading system. Moreover, it seemed to be a foregone conclusion, that whatever type of loading method would be used, it had to be a closed loop servo system. After all,

FIGURE 1

TIRE TESTING MACHINE (HYDRAULIC)

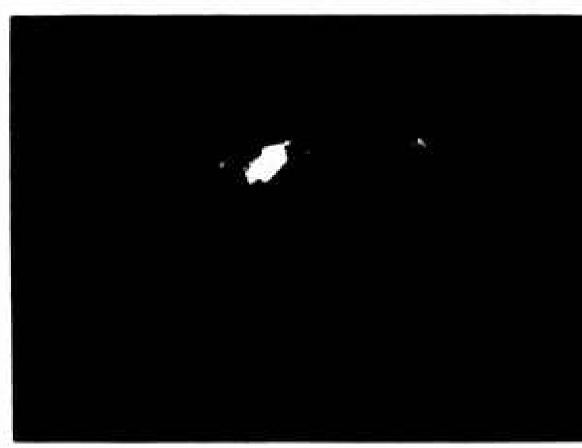

FIGURE 2

TIRE TESTING MACHINE (DEAD WEIGHT)

how else can one hold an applied load constant under varying pressure conditions. Consequently, machines were built based on servo systems which controlled either screw type or hydraulic loading systems. The results were far from satisfactory. The load which the system had to control consisted of an inflated rolling tire which exhibited features generally associated with springs. This property of the tire caused the servo system to overshoot the set point which frequently resulted in "hunting", that is, over correction and oscillation of the servo system. Moreover, tire force variations and long duty cycles (endurance tests can last up to 90 hours) placed high demands on the servo system and its associated electronic and mechanical subsystems, resulting in high failure rates.

It did not take long to realize that closed loop motor driven screw loading servo systems performed worse than piston type hydraulic systems. The motorized screw could not react fast enough, which caused large excursions around the load set point. These excursions exceeded the D.O.T. specifications which made the designers abandon the simpler screw type system and settle on the more complicated but faster hydraulic approach. Sophisticated electronic servo circuits had to be designed to assure correct servo action under the adverse conditions encountered by tire test machines.

Special servo valves were developed which had to withstand the continuous demands of the servo systems over prolonged periods. And yet, in spite of all these improvements, hydraulic servo tire loading systems continue to break down frequently, causing lost test time and excessive maintenance costs.

Serious doubts were raised as to whether the hydraulic systems were indeed designed to meet the specific test requirements and idiosyncracies of tires. It rather seemed that dead weight systems were replaced by hydraulic systems without the use of a thorough analysis of the task at hand. It was, therefore, decided to launch an investigation to cover the following points:

1. Review existing tire loading machines and their relative merits.
2. Analyze tire response and machine performance during typical tire endurance tests.
3. Determine absolute requirements of loading systems necessary to meet D.O.T. endurance specifications.
4. Based upon above conclusions, determine if a simple reliable loading system can be developed.
5. If affirmative – design said system and build prototype.

The conclusions based on steps 1 through 4 pointed out that it should be possible to design a loading system, which would perform all necessary functions, yet would be far simpler in design than present day hydraulic systems. Consequently, a prototype loading system was designed, built and put into operation in the Uniroyal Test Wheel Department.

The performance of the prototype met all design criteria. The controlled load stayed well within D.O.T. specifications and tolerances. The prototype accomplished these functions in a simple straight forward manner, without having to resort to complicated hydraulic closed loop servo systems. Because of its simple and rugged design, excessive downtime as experienced with hydraulic systems is practically non-existent. Since the system is basically an electro mechanical system, it can readily perform automatic load changes. Additional electronic circuits detect the onset of incipient failures in the tire, and provide means to truncate the test. In summary, the system is on par with commercial systems with respect to D.O.T. specifications, but outperforms these systems in efficiency and reliability.

HISTORY

The tire industry uses a variety of tire endurance test machines which employ different loading techniques. In general, those loading techniques fall into two categories:

1. Dead Weight Loading
2. Hydraulic or Air Cylinder Piston Thrust Loading

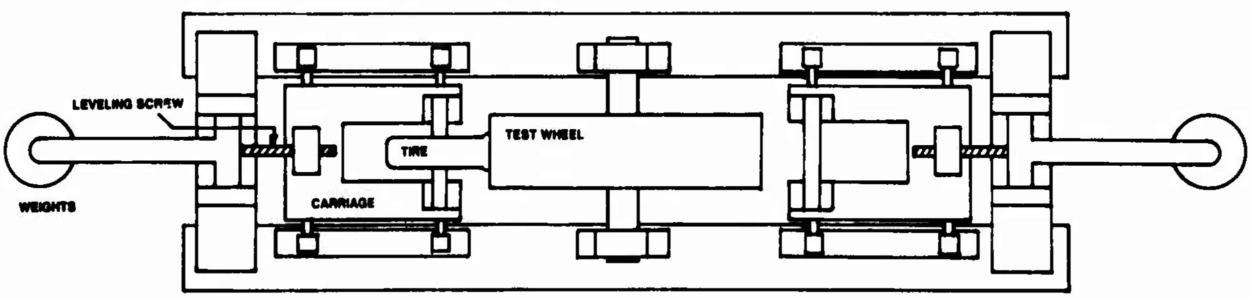

FIGURE 3

"GOVERNMENT" MACHINE (TOP VIEW)

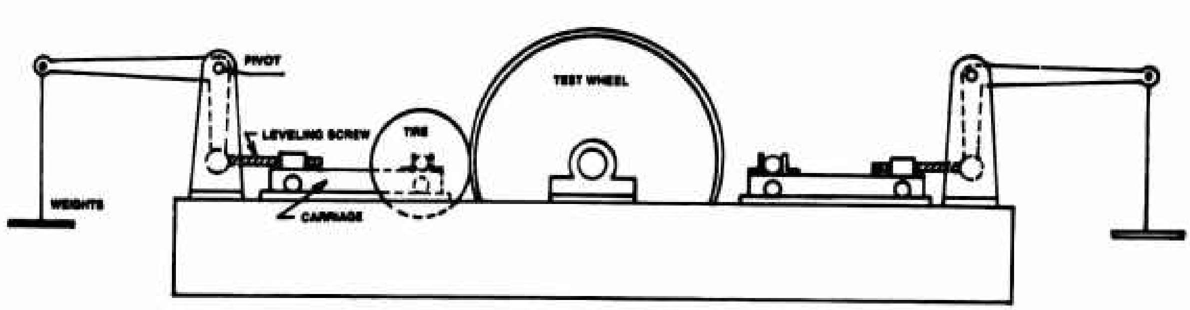

FIGURE 4

"GOVERNMENT" MACHINE (SIDE VIEW)

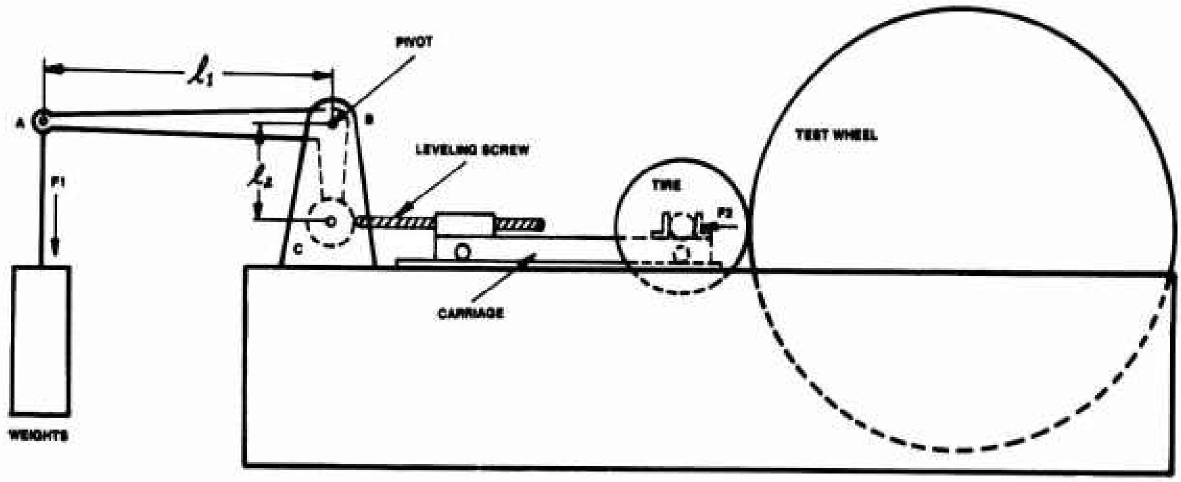

FIGURE 5

DEAD WEIGHT LOADING SYSTEM, "GOVERNMENT" MACHINE

Dead Weight Loading

Machines which use dead weight loading invariably utilize mechanical leverage systems with different arm ratios to apply the load to the tire. The Government carriages, McNeil carriages, Adamson machines, passenger Flat Belt and Lateral Thrust machines belong into this group. Since all of these machines use the same basic method but differ only in the application of same, it suffices to describe the operation of one typical machine in order to explain the underlying principles of the dead-weight loading group.

Figures 3 and 4 depict the top and side view of the Government machine* which uses the dead weight loading principle. The tire is mounted on a movable carriage which is forced towards the roadwheel through a lever-weight system.

As can be seen from the enlarged section in Figure 5, the moments in the X and Y axis around the fulcrum (B) of the rigid lever are $F_1\ \ell_1$ and $F_2\ \ell_2$. Note that the lever is designed such that AB ⊥ BC

At equilibrium $F_1\ \ell_1 = F_2\ \ell_2$ (1)

or $F_2 = F_1 \frac{\ell^1}{\ell^2}$ (2)

where F_1 is the force due to the applied weight (W) and F_2 is the force exerted by the roadwheel perpendicular to the tire axle, ℓ_1 and ℓ_2 are the respective lengths of the levers as measured from the fulcrum (AB and BC). Generally, the relationship between ℓ_1 and ℓ_2 is 3:1. This means that in order to load the tire with 1800 lbs., only 600 lbs. have to be applied at point A of the lever.

The above relationship (1) is true only if lever AB is balanced horizontally. Although the applied load (e.g. 600 lbs) does not change under imbalance conditions, the test load will be affected by the imbalance. It is, therefore, imperative to carefully balance the system in order to apply the correct load to the tire.

*So called, because these were the first tire testing machines built according to Bureau of Standards' specifications.

As mentioned, all dead weight loading systems use the principle of leverage in order to reduce the weights to manageable units. To illustrate this point, we shall show two more machines; the Overhead Adamson machine Figure 6, and the McNeil Carriage, Figure 7.

Although the design of these machines differs considerably from each other and from that of the Government machine, the underlying principle is the same. In each case, we see again the levers ℓ_1 and ℓ_2, the pivot point B and the levelling screw E.

Hydraulic Piston Thrust Loading

Machines belonging into this category replace the dead weight with a hydraulic cylinder-piston mechanism. The load-cylinder centerline concurrently intersects the tire spindle centerline at 90 degrees and the center of the tire both radially and in the plane of the tire. Thus, the force of the cylinder rod is the load on the tire. Figure 8 shows the essentials of a typical hydraulic machine. The tire is mounted on a spindle which is attached to a movable carriage. The carriage is free to move horizontally on two round ways, one mounted directly above the other. Ball bushings per way keep the drag low. The cylinder is flange mounted to the machine's end frame. The piston rod attaches to the carriage by means of a self-aligning rod end.

The loading system common to the machine just described and any other brand of hydraulic loading machines thus contains the following components:

- Pump Motor
- Hydraulic Pump
- Reservoir and Filter
- Oil Temperature Control System
- Check Valves and Control Valves
- System Pressure Regulator (Open Loop) or Feedback Regulation (Closed Loop)
- Load Cylinder

Modern type hydraulic loading machines invariably use the closed loop approach which requires in addition to the above, a hydraulic servo valve controlled by cylinder mounted load cells and electronic circuitry.

A typical servo controlled system is depicted in Figure 9.

Operation is as follows:

The required test load (T+RA) is entered as an analog voltage into one side of a comparator. The analog voltage of this command signal is amplified in a power amplifier

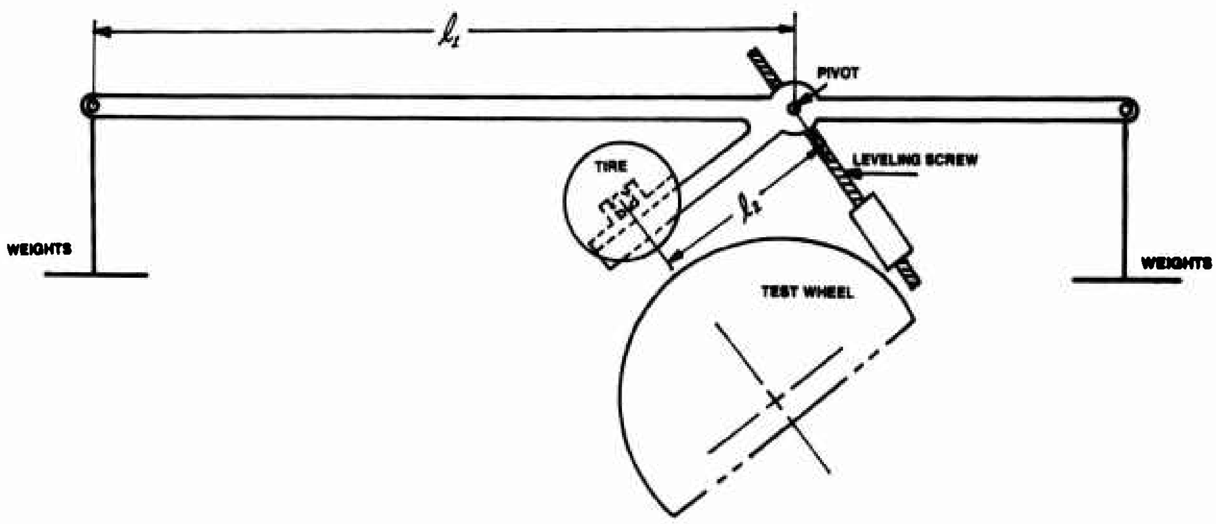

FIGURE 6

DEAD WEIGHT LOADING SYSTEM, ADAMSON OVERHEAD MACHINE

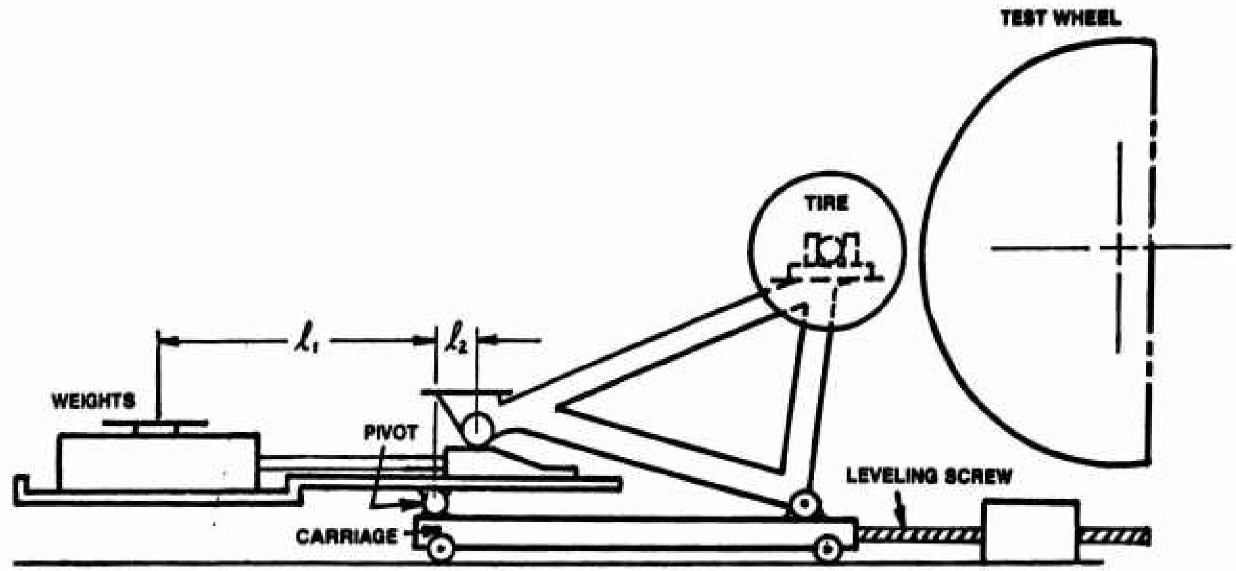

FIGURE 7

DEAD WEIGHT LOADING SYSTEM, McNEIL CARRIAGE

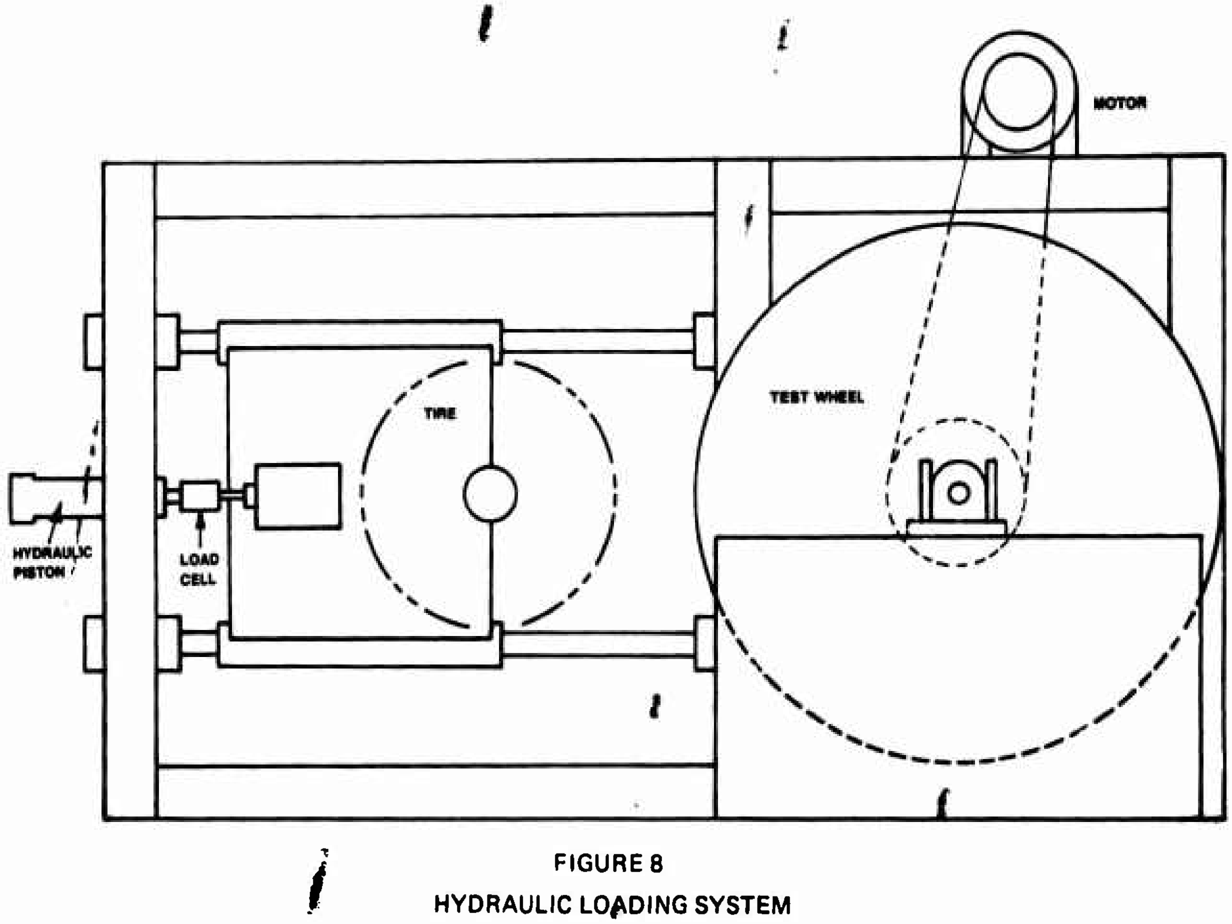

FIGURE 8

HYDRAULIC LOADING SYSTEM

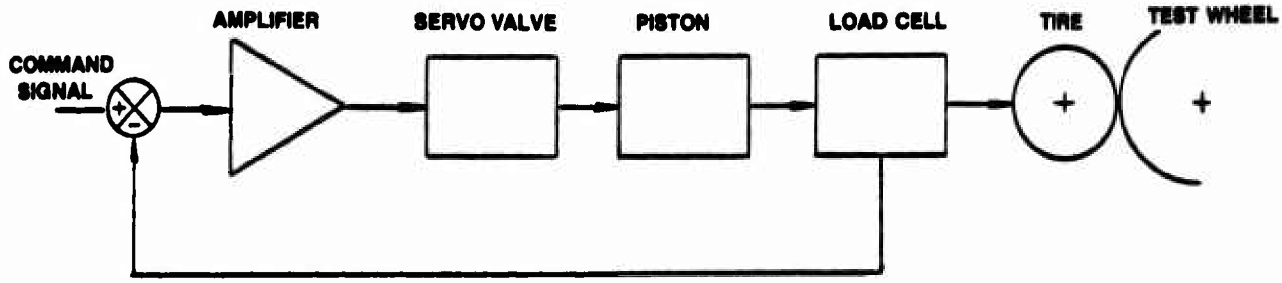

FIGURE 9

SERVO CONTROL SYSTEM

which drives the servo valve. The servo valve controls the hydraulic fluid flow which in turn actuates a hydraulically operated piston. The piston drives the tire assembly against the roadwheel until the correct load, as sensed by a load cell, is reached. The load cell signal is compared to the command signal and if both are equal, the servo valve will maintain the required load. A change in command signal or load cell feedback signal will result in an error signal. This error signal causes the servo valve to correct the load until the error signal is reduced to zero. At that point, the system reaches a condition of equilibrium.

Feedback is necessary in any control system that must provide accuracy and response. Feedback is absolutely essential in any application using an electro hydraulic servo valve because of null bias present in all servo valves. We shall come back to this point in a later part of this paper when we compare the merits of electro hydraulic servo systems versus the merits of the system as described in this paper.

In order to correctly assess the part the loading system plays in the overall system of a tire endurance testing machine, an understanding of the FMVSS endurance test is essential. The following is a brief version of the D.O.T. 109 test.

FMVSS 109

Tires designed for highway use on passenger vehicles, trucks, buses, trailers and motorcycles are subject to testing in accordance with Federal Motor Vehicle Safety Standards (FMVSS 109 or FMVSS 119).

These standards require the determination of minimum tire performance levels when same are tested on smooth flywheels. Two tests are performed: Endurance (a step-up load test) and High Speed Performance (a step-up speed test).

Tests are conducted on 67.23" diameter smooth steel flywheels (one revolution of the flywheel gives 1/300 mile tire travel). The flywheels must be at least as wide as the tread of the tire under test. The ambient temperature should be 100°F.

The U.S. Dept of Transportation specifies the operating tolerances of the FMVSS test parameters as follows:

Tire Load in pounds		+0 to -40 lbs.
Tire Speed in MPH		+0 to - 2 MPH
Test Area, Temperature in °F		± 5°
Tire Inflation Pressure		+2 to -0 PSI
Time (Cycles)		
4 hours	+0 to - 2 minutes	
6 hours	+0 to - 3 minutes	
24 hours	+0 to -10 minutes	

It is further specified that the load reading in pounds must be made from load cells located directly on or adjacent to the test tire axle. Load cells located on the test tire carriage are acceptable provided the load recording indicates when the tire is actively engaged or disengaged from the test wheel.

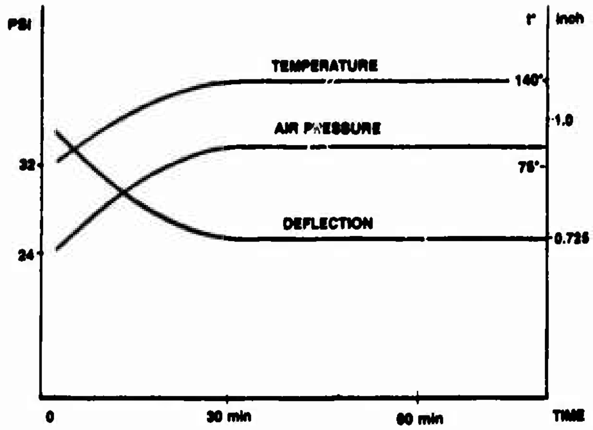

FIGURE 10

TIRE PARAMETERS CHANGE
DURING ENDURANCE TEST

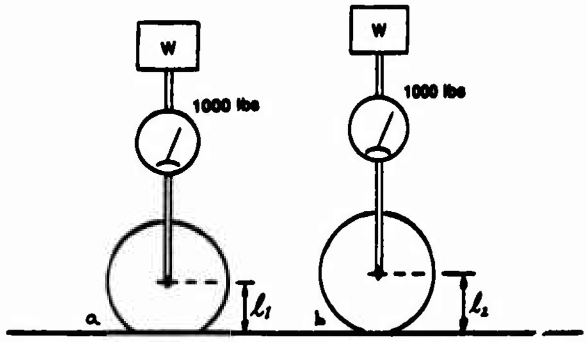

FIGURE 11

CONSTANT LOAD (SEE TEXT)

Immediately after running the tire the required time, the inflation pressure is measured. Tire pressure at the end of the test shall be no lower than starting pressure. After cooling the tire for one hour, it is removed from the test rim and visually inspected. After completion of the endurance test, the tire shall have no tread, sidewall, innerliner, ply, cord, or bead separation, chunking, broken cords, cracking or open splices. Thus far the FMVSS specifications.

It is interesting to note that the specified load regulation is given as a fixed maximum quantity by which the applied load may vary (+0 to -40 lbs). In terms of percentage load regulation, this means that at low load, the regulation can be as high as 4%, whereas at the high end of the tire load spectrum, regulation may have to be better than 1%.

A second point of interest is the determination of the tolerance limits, namely +0 lbs. and -40 lbs. This means that the applied load is not allowed to vary by any amount above the specified test load, but can vary by as much as 40 lbs. below that value. Closed loop systems, which of necessity have a ± excursion around the load set point cannot run the tire at the exact test load, but have to adjust the load to a value which is below the test load by a certain amount. This may not be detrimental at high loads, but will introduce a significant error at low loads. Thus, the D.O.T. specifications present a formidable problem to closed loop servo systems, which is not easily solved by conventional means.

The Behavior of the Tire During a Typical Endurance Test

In order to gain a better understanding of the design criteria for the construction of an automatic tire test loading system, one has to analyze the various factors which influence the performance and accuracy of the system. One of the major factors the loading system has to contend with is the change of the tire's parameters during an endurance test.

Figure 10 shows typical temperature, pressure and deflection curves which were obtained with a tire loaded at T&RA load against a roadwheel at a rotational speed of 50 mph. The starting inflation was 24 psi. It is generally assumed that the following chain of events takes place: Due to the hysterestic losses in the tire materials, heat is generated. The air inside the tire cavity will reach a higher average temperature than at the beginning of the rolling process due to heat conduction, and this causes a higher pressure than the original inflation pressure of the tire due to the increased temperature of the trapped air. This pressure rise causes a reduction in tire deflection which in turn slows down the rate at which the temperature increases. In addition, the hysteresis characteristics of the visco-elastic tire materials also generally decrease with higher temperature. These interactions, while complicated, all tend to cause the deflection to decrease as time goes on, until equilibrium conditions are reached. At the point of thermal equilibrium, the rate of heat generated in the tire is equal to the rate of heat dissipated into the outside world through convection, conduction and radiation. From that point on, the deflection of the tire stays constant throughout the remainder of the endurance test, unless of course, the development of an abnormal condition in the tire changes the thermal equilibrium point.

Deflection and Load

The change in the tire deflection directly affects the test load, except in the case where the load is applied vertically to the tire and is not obstructed in its movement in the vertical plane. The following figures (11, 12) compare dif-

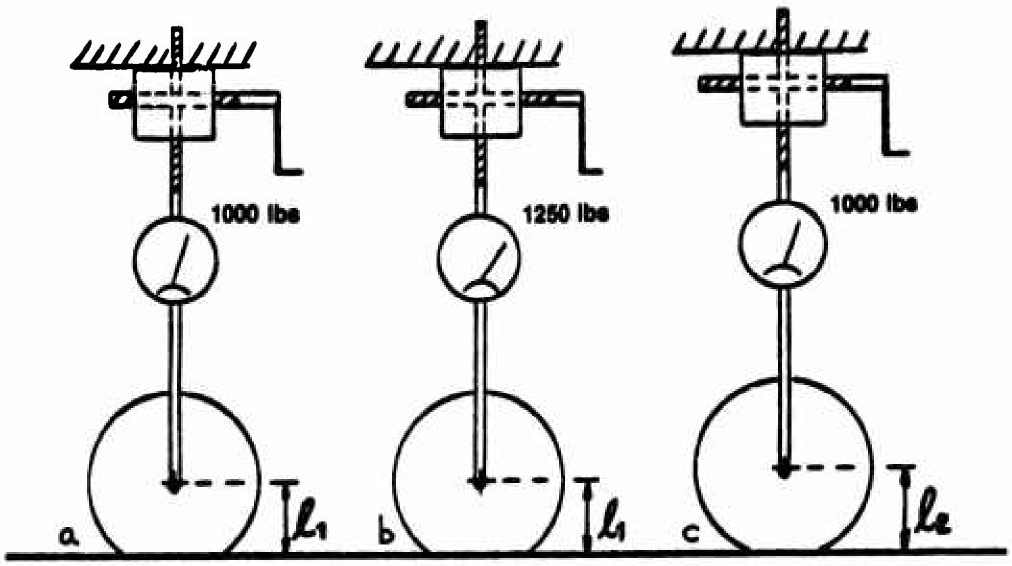

FIGURE 12

a. COLD TIRE LOAD
b. TIRE LOAD AFTER WARMUP
c. RE-ADJUSTED LOAD

ferent methods of load application and their respective means to keep the load constant under varying tire deflections.

Figure 11 shows a vertical load applied to the tire. At the cold inflation pressure, the tire deflection caused the tire axle to be above ground by a distance ℓ_1. After warmup, (Figure 11b), the deflection decreased with the result that the tire axle moved up assuming a new distance of ℓ_2 above ground. The weight (load) on the tire moved up by the same amount and obviously did not change its value. Under those conditions, the load stays constant and is not affected by changes in tire deflection.

Let us now again apply the load vertically, but instead of a weight we shall use a screw type loading system. (Figure 12)

The load is adjusted to 1000 lbs. by turning the screw until the load indicator shows that amount. Inflation pressure is 24 psi (cold) and axle height is ℓ_1. After warmup, the increased inflation pressure (32 psi) appears as an addition to the 1000 lbs. force and the tire experiences a resultant load of 1,250 lbs. (Figure 12b)

In order to return to the original test load, the screw is backed up until the load indicator shows 1000 lbs. Measurement of the axle height now shows ℓ_2 (Figure 12c) which is the same distance as shown in Figure 11b for a warmed up tire under non-restricted load conditions.

The principle just described applies to any type of loading system, and either manual or automatic load regulation has to be performed in order to compensate for the increase in tire inflation pressure during the warmup period.

In the case of dead-weight systems, as for instance the government machine, the decrease in tire deflection causes carriage (D) to move toward lever BC. (See Figure 5) This causes levers BC and AB to move out of the balance position with the result that the tire test load has now changed from the required value to an incorrect value. To rebalance the system, the distance between the carriage D and the lever BC has to be decreased by an amount equal to the change in deflection. In practice, this is accomplished by turning levelling screw E until lever AB is again levelled.

In the case of electro-hydraulic servo systems (See Figure 9) it is the load cell which senses an increase in test load because of an increase in inflation pressure. An error signal is thus created and a command is given to the piston to back up until the load cell again senses the required test load.

Load Regulation

Armed with an understanding of the interaction between tire inflation pressure and test load, we shall now proceed to analyze the performance of the load regulation system during a typical tire endurance test.

Figure 13 shows test load deviations from the nominal test load taken over a major part of the endurance test period. The test load graph is typical of dead weight loading systems where the adjustment is performed manually.

A typical test sequence is as follows:

The test starts with the tire under the correct T&RA load. Within minutes, the tire begins to warm up which is reflected in an imbalance of the loading system. The first adjustment is performed at approximately 15 minutes after the start of test, bringing the test load back to normal. The tire continues to warm up, and another adjustment is performed. Typically, after 45 minutes, the tire has reached a thermal equilibrium state. Another adjustment is made and from that point on inflation pressure stays constant. Consequently, there is no further need for additional adjustment of the test load for the remainder of the test.

Automatic loading systems perform the regulation in precisely the same way. Figure 14 shows the relationship between tire inflation, piston travel and regulated test load. The curves are typical for any hydraulic servo loading system. The piston is backing up, compensating for increasing load, thus keeping the test load constant throughout the test.

The oscillatory waveform of the test load and piston travel curves is the result of the hydraulic servo valve action. In an ideal valve, the controlled oil flow is directly proportional to the error signal, so that at zero error, control flow is zero. In a real valve, such is not the case. A slight error signal so-called null bias is required to bring the valve to null. This action of the servo causes a continuous flow of oil into and out of the loading cylinder, with the result that the loading system is never at rest during the entire endurance test.

Be this as it may, the basic performance of any of these loading systems is the same and is governed by the following two criteria:

1. Tire load increases because of increase in inflation pressure.

2. Tire load stays constant at thermal equilibrium.

This leads to the following important conclusions:

1. Load regulation has to occur in one direction only (decrease load).

2. Load regulation is not necessary after thermal equilibrium has been reached.

These conclusions in conjunction with D.O.T. specifications provided the basis for establishing the minimum necessary requirements which had to be met by a tire loading system. Namely:

1. LOAD RANGE	300 lbs. to 3000 lbs.
2. LOAD ACCURACY	+0 to -40 lbs. at any setting
3. LOAD REGULATION	Uni-directional
4. DUTY CYCLE	System to be operative only when regulation is required.

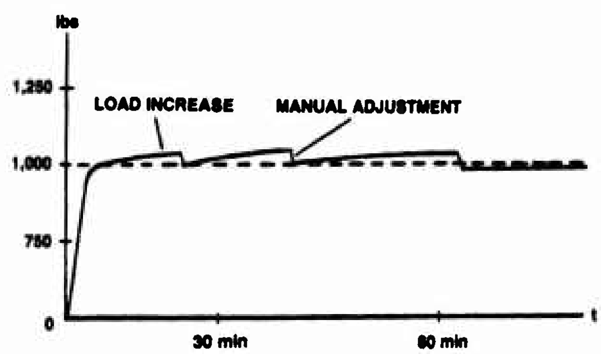

FIGURE 13
TYPICAL TEST LOAD CURVE WITH DEAD WEIGHT LOADING SYSTEMS

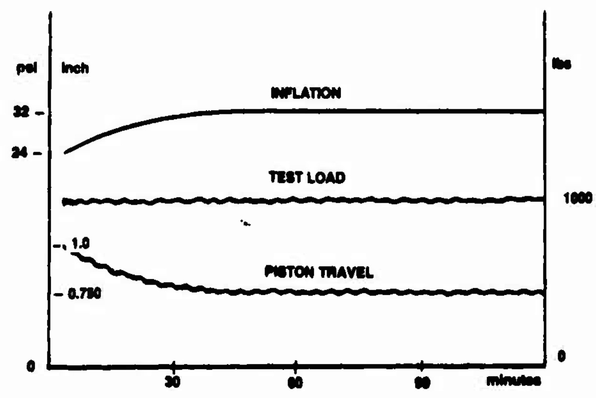

FIGURE 14
TYPICAL TEST LOAD CURVES WITH AUTOMATIC LOADING SYSTEMS

5. LOAD CHANGE — Automatic and programmable

6. CONSTRUCTION — Rugged and simple

The rationale for these six requirements is as follows:

1. **LOAD RANGE**

   The load range depends on the type of tires to be tested. The load range of 300 lbs. to 3000 lbs. is for passenger car tires.

2. **LOAD ACCURACY**

   The degree of accuracy needed in keeping the required test load is based on D.O.T. specifications.

3. **LOAD REGULATION**

   Analysis revealed that regulation is required in one direction only. That is, during the early part of the test, the load on the tire is continuously diminished in order to compensate for increase in tire pressure. It should be mentioned at this point that uni-directional regulation will always occur under normal operating conditions, provided that ambient temperature and speed remain constant and no air loss occurs in the tire. Under varying operating conditions, thermal equilibrium will change and may cause an increase or decrease in inflation pressure and/or test load. However, abnormal conditions a priori mean that the test should be truncated since it does not conform to D.O.T. specifications.

4. **DUTY CYCLE**

   The system performing the load regulation should be active only when called for. This is advisable for any servo regulation system but more so for a tire endurance test regulation system since it has been shown that the major part of the test does not require regulation at all. In other words, energy should be expanded by the system only when regulation is performed.

5. **LOAD CHANGE**

   FMVSS 109 and 119 call for a number of load changes during the SUL (stepped up load) cycle. The system should be capable of automatically stepping up the load to a pre-programmed new test load value when so desired.

6. **CONSTRUCTION**

   Construction has to be simple and rugged. Tire endurance tests are performed under severe and adverse conditions. The employment of delicate control units and instruments should be avoided. Operation must be reliable and virtually maintenance free.

Evaluation

Having thus established the minimum absolute requirements for an automatic tire loading system, we shall now proceed to evaluate existing loading systems in the light of these criteria. The results are tabulated in Chart I.

EVALUATION OF COMMERCIAL LOADING SYSTEMS

TYPE OF LOADING	METHOD	REGULATION	ADJUSTMENT	POWER REQUIRED	RELIABILITY	ADVANTAGE	DISADVANTAGE
DEAD WEIGHT	WEIGHTS LEVERS	± 5 lbs	MANUAL	NONE (GRAVITY)	EXCELLENT	MINIMAL MAINTENANCE	MANUAL ADJUSTMENT, BULKY, NON-PROGRAMABLE, NO LOAD READOUT
PISTON THRUST	CLOSED LOOP HYDRAULIC SERVO SYSTEM	± 10 lbs	AUTOMATIC	POWER CONSUMED DURING ENTIRE TEST	POOR	EASE OF OPERATION, PROGRAMABLE, LOAD READOUT	EXCESSIVE BRKDWN MAINT. PROBLEMS, CONTINUOUS WEAR-TEAR, NOISE POLLUTION
MECHANICAL SCREW	CLOSED LOOP SERVO CONTROLLED DRIVEN SCREW	± 20 lbs	AUTOMATIC	POWER CONSUMED DURING 90% of TEST TIME	FAIR	EASE OF OPERATION, PROGRAMABLE, LOAD READOUT	DEAD ZONE PROBLEMS, HUNTING, CONTINUOUS WEAR-TEAR

TABLE I

Design Guide Lines

The information thus far presented, inevitably led to the followinng conclusions and design guide lines.

1. Since there is no need for load regulation in both directions, there is no need for sophisticated hydraulic servo systems. This eliminates in one fell swoop severe maintenance problems caused by continuous wear and tear on pistons, delicate servo valves, contamination of hydraulic oil, leakage, etc., etc.

2. Uni-directional load regulation also eliminates the need for closed loop servo controls as used with motor driven screw type systems. Although these systems are designed to stop the screw action within a certain "dead zone", thus improving efficiency, it turned out that the electrical adjustment of the dead zone was very critical, resulting in an unreliable regulation.

3. Automatic load control is superior to dead weight loading. It eliminates the need for heavy weights to be manipulated by the operator.

As dictated by the design guide lines and conclusions, the final design resulted in a straight forward, simple, loading system which is operated by the following:

1. Motor driven screw type loading.

2. Uni-directional automatic load regulation.

3. Programmable load change control.

The heart of the system is a directional control unit which sees to it that regulation takes place in one direction only. Moreover, this unit also assures that regulation occurs only when called for, thus providing a highly efficient system.

Figure 15 shows an operational flow diagram of the system.

The required load is dialed in and appears as an analog voltage at comparator C. The load cell which is mounted in line with the loading screw supplies the analog tire load signal which is to be compared with the dialed-in load in comparator C. As long as these two signals are not equal, comparator C provides an output signal which is amplified and passed through the directional control to motor M. The loading screw, driven by motor M, will move the tire against the roadwheel until tire load equals dialed-in load. Bypassing the directional control makes the just described control system look exactly like a typical closed loop servo system. It is the introduction of the directional control which changes the universal closed loop servo system to a system which is optimized for the task at hand, namely, regulating the load for tire endurance testing purposes.

Action of the directional control is best explained with the aid of Figure 16.

Let us assume that a test load of 1000 lbs. is required and has been dialed-in. Initially, the directional control has set the motor rotation into the clockwise mode, thus driving the loading screw forward with the result that the tire is being loaded. When the tire load equals 1000 lbs., the comparator output equals zero. This zero crossing signal is used to cause the directional control to reverse the rotation of the motor and to stay in that mode for the remainder of the test. As the tire warms up, the test load increases, causing an error signal. As explained previously, this signal causes the motor to operate and turn the screw in a counter clockwise direction until the test load again equals the dialed-in load.

There is a slight overshoot because of inertia in the system causing the regulated load to settle at approximately 5 lbs. below the set point. The tire continues to warm up and the test load again crosses the dialed-in load level, causing another cycle of load regulation. These cycles continue until thermal equilibrium is reached at which point no further regulation is required.

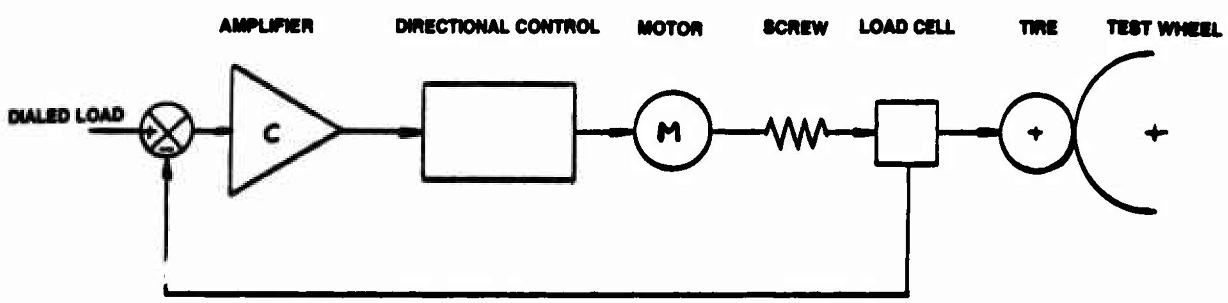

FIGURE 15

OPERATIONAL FLOW DIAGRAM (SEE TEXT)

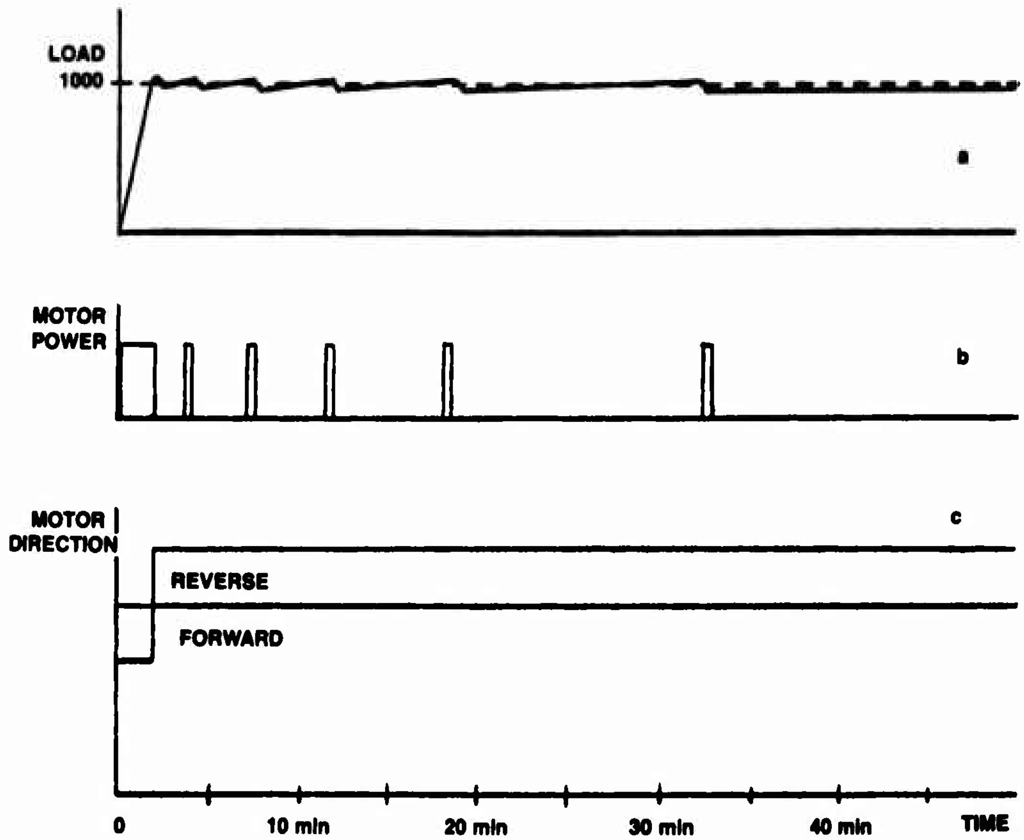

FIGURE 16

TYPICAL REGULATION PATTERN WITH UNI-DIRECTIONAL LOAD CONTROL (SEE TEXT)

The remarkable reduction in motor power consumption is shown in Figure 16c. The motor is required to operate only when the test load exceeds the predetermined level, and then only for the short time needed for backing up the screw. In between these points, the motor is shut off completely. Since most of the test is conducted in an equilibrium state, the motor and associated mechanical members are hardly used, resulting in an excellent reliability of the system. It is, of course, the introduction of the directional control, which, by allowing load regulation in one direction only, enabled the design of a reliable and rugged loading system. And this, we believe, would not have been possible without a detailed analysis of the endurance test as presented in this paper.

Although not originally intended, the uni-directional method yielded two additional important features:

1. Detection of change in test conditions as caused by air loss, ambient temperature, roadwheel speed, etc.
2. Detection of the onset of incipient failure, which enables a truncation of the test before tire destruction.

A discussion of these features will follow the next chapter which describes the electronic circuitry of the loading system.

Electronic Control Circuits

A functional block-diagram of the electronic portion of the loading system is presented in Figure 17. The design is straight forward and utilizes off the shelf items such as signal conditioners, motor control units, etc.

Figure 18 shows a diagram of the complete circuit. Load regulation, load programming, incipient failure and abnormal condition detection are all accomplished with the aid of three op-amps, a few transistors and five relays. It is not the intent of this paper to give a detailed description

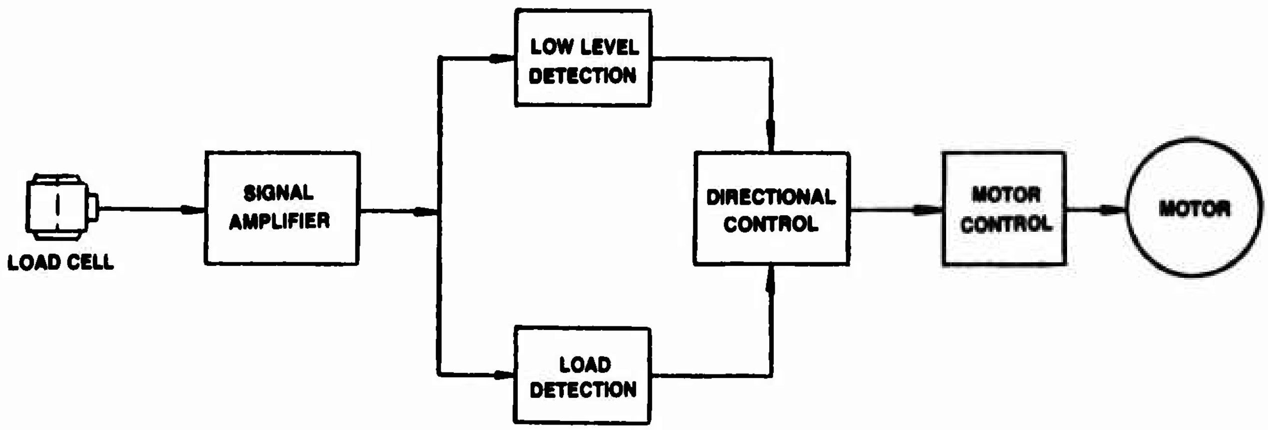

FIGURE 17
FUNCTIONAL BLOCK DIAGRAM

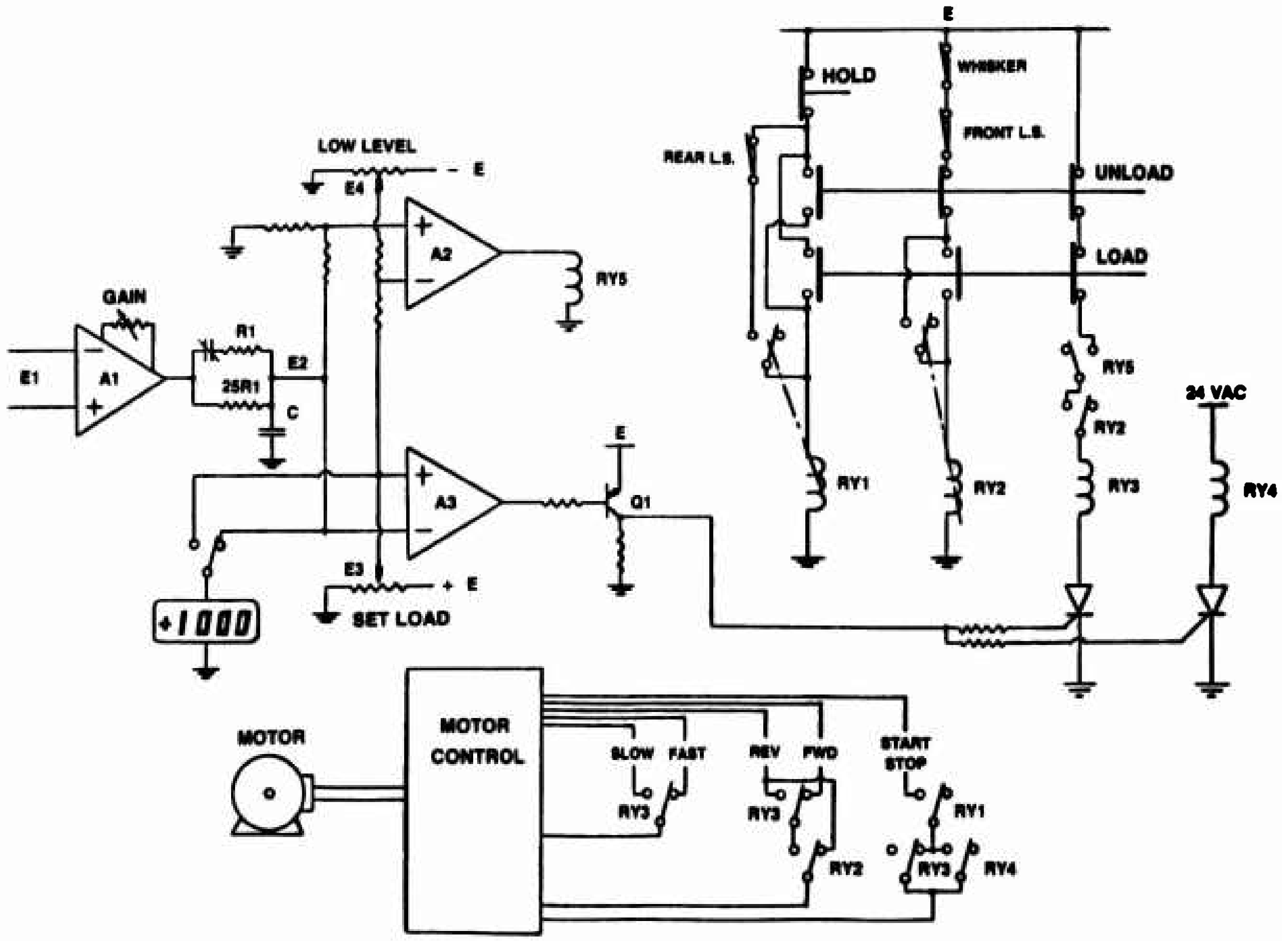

FIGURE 18
ELECTRONIC DIAGRAM OF UNI-DIRECTIONAL CONTROL

of the circuit. However, some explanation is necessary in order to understand the detection features.

The output signal of the load-cell (which senses the applied test load) is amplified in a special instrumentation amplifier A_1. The gain is adjusted to provide 1mV per 1 lb. load. The amplified signal is filtered (force variations are removed) and is then applied to the input of amplifiers A_2 and A_3. Amplifier A_3 compares the load cell signal with an analog load setting signal E_3. When the load cell signal exceeds the set load E_3, amplifier A_3 changes its output polarity and causes relays RY_3 and RY_4 to pull in. Relay RY_3 is the previously described uni-directional control. Its function is to change the direction of the screw loading motor into the reverse mode and slow down the rotational speed of same. The relay will stay locked for the remainder of the endurance test, thus keeping the motor in the reverse mode and allowing only backup motion of the screw if regulation is required. Relay RY_4 will turn the motor off when the screw has backed up sufficiently to return the load cell signal to just below the set load signal.

Monitoring the action of Relay RY_4 provides an excellent record of the tire's behavior during the test. Analysis of the frequency at which RY_4 is operating provides the basis for the incipient failure detection. Operational amplifier A_2 is used to detect an excessive decrease in test load, that is more than the allowable -40 lbs. as specified by D.O.T. The amplifier is wired up as a voltage comparator, the voltages being the analog test load voltage (E_2) and a voltage produced by subtracting a constant voltage (E_4) equivalent to 40 lbs. from the dialed in test load (E_3). When the test load voltage E_2 falls below this low level (E_3-E_4) the amplifier changes polarity and activates relay RY_5. The action of relay RY_5 is used in two ways. It signals the operator that a change in test conditions has taken place and, if so desired, causes the screw loading motor to change direction and drive the tire towards the test wheel until the correct test load has been obtained. At this point, the uni-directional Relay RY_3 takes over and operation reverts back to normal as previously described.

The remainder of the circuit diagram as depicted in Figure 18 contains the digital read-out, various safety limit switches, the motor control unit, and the motor. The "fail-safe" approach was used wherever possible, that is, loading the tire against the roadwheel can occur only with relays in the energized state and limit siwtches in the normally closed position.

Incipient Failure Detection

It has been shown in the literature and elsewhere (4, 5) that the majority of developing tire flaws are accompanied by an increase in tire temperature. In fact, this phenomenon

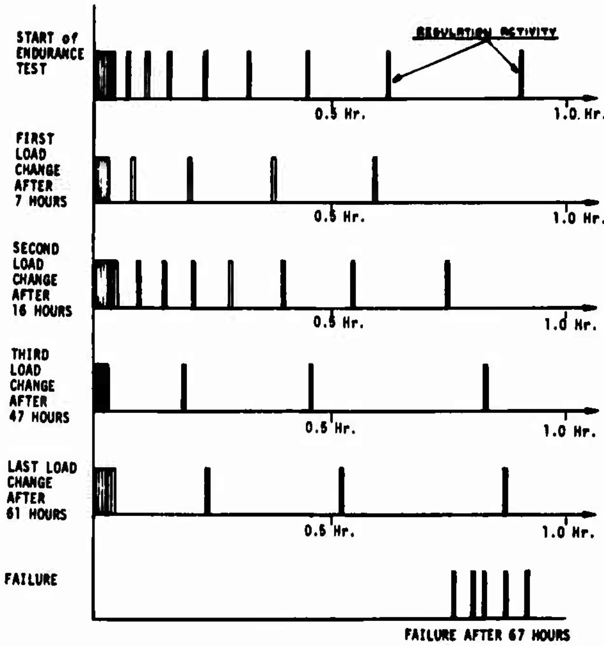

FIGURE 19

INCIPIENT FAILURE DETECTION THROUGH OBSERVATION OF LOAD REGULATION ACTIVITY

served as the basis for the development of the Monsanto TFD system (6). An increase in tire temperature causes an increase in tire pressure with the result that relay RY_4 is energized in order to initiate load control action. Figure 19 shows copy of an actual recording of RY_4's activity during an entire endurance test with stepped load changes. Activity is very pronounced during the first 10 minutes of the start of the test and for the same period of time after the start of the endurance test. As can be seen on the last part of the recording, relay RY_4 began to show activity very close to the point where the test terminated. Termination in this case was caused by destruction of the tire.

A sizeable number of endurance tests were performed and records of relay activity obtained. In almost all cases relay activity started with incipient failure and continued towards the point of destruction of the tire. Based on these findings, a number of endurance tests were terminated when increased relay activity pointed out the possible development of tire failure. Subsequent analysis confirmed that indeed incipient failures were present in those tires. The method thus provides a means for studying the propagation of the incipient failure in far greater detail than would have been possible under normal testing where the destruction of the tire in many cases masks the starting point.

Detection of Change in Test Conditions

As has been pointed out, thermal equilibrium in the rolling loaded tire will be obtained under normal conditions, namely, controlled ambient temperature, constant test wheel speed and no air loss in the tire during the test. Any change in these conditions will manifest itself in a change of the test load. In general, ambient temperature and rotational speed of the test wheel are well controlled and do not present a serious problem. Air loss, however, is a common occurrence, and the test must be terminated if air leakage has been established. Since test load is directly proportional to tire air pressure, a decrease in air pressure will result in a decrease of test load.

The uni-directional method of the loading system prevents load regulation during a decrease in load. This feature made possible the detection of air loss by simply monitoring the progression of a decrease in test load and trigger an alarm when the test load has reached a pre-determined low value. In practice this has worked out very well. The alarm system has aided in terminating tests where tires developed slow air leakage. With regular closed loop hydraulic servo systems, this detection would not be possible, thus causing many hours of wasted test time.

In Summary

A description of a unique loading and control system for tire endurance testing machines was presented. Analysis of tire behavior during endurance tests led to a non-conventional approach in designing a system which, being simple and rugged practically eliminates downtime and maintenance problems. Versatility of the system is further enhanced through the addition of electronic circuits which detect incipient tire failures and abnormal test conditions. Provision has been made to truncate the test at the onset of incipient tire failure. Massive failure is thus prevented, enabling a detailed analysis of the cause of failure and its progression.

ACKNOWLEDGMENTS

Acknowledgment must be made of the very skillful execution of all experimental phases of the described project by K. L. Bine of Uniroyal, Inc. His diligence and original ideas contributed greatly in bringing this project to a successful ending.

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LABORATORY MEASUREMENT OF PASSENGER CAR TIRE TREAD WEAR

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ABSTRACT

One-thousand mile wear tests were conducted on Calspan's Tire Research Facility using preselected G78-15 and GR78-15 tires representative of low mileage and high-mileage specimens. A tire test schedule was devised that achieved (a) tread surface textures similar to road-worn tires, (b) uniform cross-tread wear and (c) predictable wear rates. Tire wear was measured using sensitive electro-mechanical tread-depth sensors. The test data verified the ability of the laboratory method to rank order the test specimens in accord with their selected basis as low- and high- mileage tires. Operational experience is noted and recommendedations for technique improvement are proposed.

TIRE TREAD LIFE ranks among the important factors that determine tire quality since it involves considerations of safety and operating cost. Attesting to the importance of tread life is the proposed Uniform Tire Quality Grading Standard of the National Highway Safety Administration which includes a provision for tread wear grading of new tires.

A direct approach to determining tire tread wear rates is to conduct vehicle mileage accumulation tests over regular highways or special test courses. Despite its apparently compelling simplicity, this approach has some serious drawbacks. In outdoor testing many important parameters that affect tread wear are not subject to control. As a result, high mileages must be accumulated on the test specimens in an attempt to minimize distortions in test data from these sources. Such lengthy tests are very expensive and attempts have been made to shorten them by artificially increasing the wear rate. Unfortunately, such expedients have not proved to be very useful since wear rates measured among tires tested under both normal and accelerated wear conditions cannot be relied upon to correlate.

As an alternative to the vagaries and expense of road tests a laboratory method has been developed at the Calspan Tire Research Facility (TIRF) (1)* that provides a reasonably short, reproducible and economical test procedure for the production and measurement of tire tread wear. Successful implementation of the laboratory method has required realistic simulation of tire wear processes occurring in normal use. In addition, the need to measure accurately tread-depth changes of the order of one mil has had to be satisfied.

The initial experimental tread wear studies were sponsored by the U.S. Army Tank-Automotive Development Center (TACOM) (2). Test results obtained from this program demonstrated the feasibility of conducting meaningful tread-wear tests on TIRF albeit only one size and one type (tread design) of tire was employed in that study.

The subsequent program devoted to tread wear studies was conducted forthe Rubber Manufacturers Association (RMA) and involved a variety of passenger car tires (3). These tires were pre-selected as having high-mileage or low-mileage wear characteristics and the principal objective was to demonstrate the capability of the laboratory tests to properly rank order these tires.

The RMA study forms the basis for this paper which describes the laboratory test procedures which were developed to achieve tire wear characteristics similar to those experienced in normal highway usage and the implementation of a technique using electro-mechanical displacement transducers to measure tread depth. Test data are presented and their significance is discussed. Operational experience is described and reommendations are suggested for further improvements to the technique.

BACKGROUND

The many difficulties which are inherent in outdoor tests designed to measure tire tread wear are well documented (4). Because it does provide a "real life" environment and since practical alternatives have not been available heretofore, the practice of road testing continues to be used. A brief summary of the pros and cons of road tests is given in Table I.

In contrast, laboratory tests provide a controlled environment, a controlled variation of tire service parameters, the feasibility of shorter tests and the direct evaluation of the relationship between service parameters and tire wear. Calspan's computer-controlled TIRF machine, Figure 1,

*Numbers in parentheses designate References at end of paper.

Table I - Road Testing of Tire Tread Wear

ADVANTAGES:

- Tests duplicate "real-life" wear conditions.
- There exists user familiarity with the test procedure.

DISADVANTAGES:

- Uncontrolled tests result in extremely large data spread.
- Tests are of long duration at normal wear rates.
- Tests are costly.
- Data are biased by vehicle factors.
- Data are characterized by a high "noise" level because of such uncontrollable influences as weather conditions, road temperature, driver inputs, etc.

is ideally suited to the conduct of indoor testing of tire tread wear. It provides a high-speed flat roadway, a six-component metric balance and is capable of generating a wide range of wear cycles under precise servo control of slip angle, torque, load and speed. In addition, a choice of roadway surfaces is available. To exploit the potential of the TIRF machine, it was necessary to develop an efficient test methodology to (a) duplicate the characteristics of road-worn tires and (b) produce a wear level of normal severity. Concomitant with these needs was the requirement for a precise and accurate means of measuring tread loss.

Table II summarizes the more important aims.

Table II - Objectives of TIRF Tread Wear Testing

- Development of a "normal severity" wear cycle (10-20 mils/kilomile).
- Demonstrated feasibility of low-mileage wear tests (1600 km or 1000 miles).
- Demonstrated wear levels of 10 to 20 mils per kilomile.
- Development/implementation of a tread-loss measuring technique accurate to 0.1 mil.
- Demonstrated correlation with road test results.

Longer range objectives include the evaluation of the dependence of tread wear on speed, load, inflation pressure and tread depth.

The initial effort towards a partial fulfillment of the objectives listed in Table II took place under TACOM sponsorship and is reported upon in detail in Reference 2. A more ambitious program using passenger car tires was undertaken for the RMA and included more explicit objectives which are detailed in the succeeding section. A complete summary of the RMA study is given in Reference 3.

TEST PROGRAM

The principal objective of the RMA test program was to demonstrate the capability of TIRF wear tests to rank order tires on the basis of tread wear. Tire test specimens were selected whose relative tread life characteristics were known. These included high-mileage radial tires (GR78-15), control bias-ply tires (G78-15) and low-mileage bias-ply tires (G78-15).

Subordinate objectives included the generation of uniform cross-tread wear, tread surface textures representative of road-worn tires and achievement of specified wear rates. Improvements in tread-wear measuring instrumentation and measurement procedures were implicit requirements in the fulfillment of these goals.

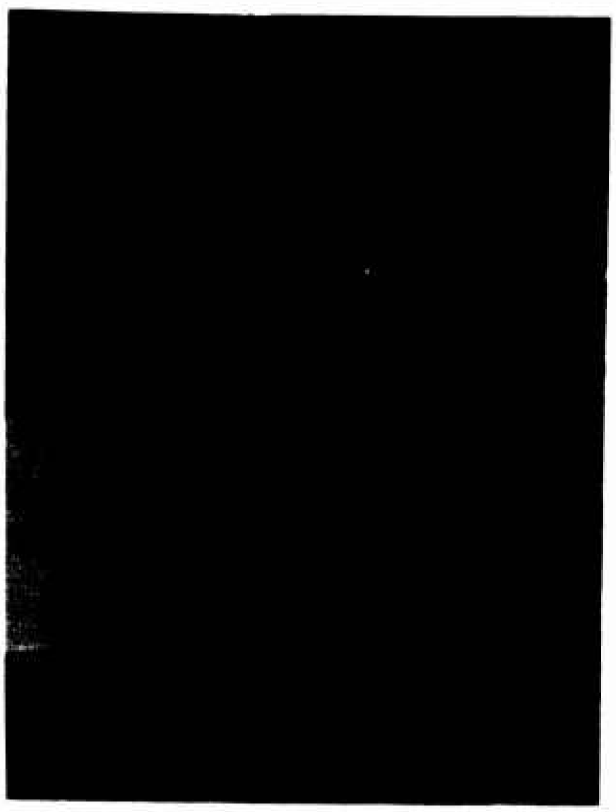


FIGURE 1 TIRF MACHINE

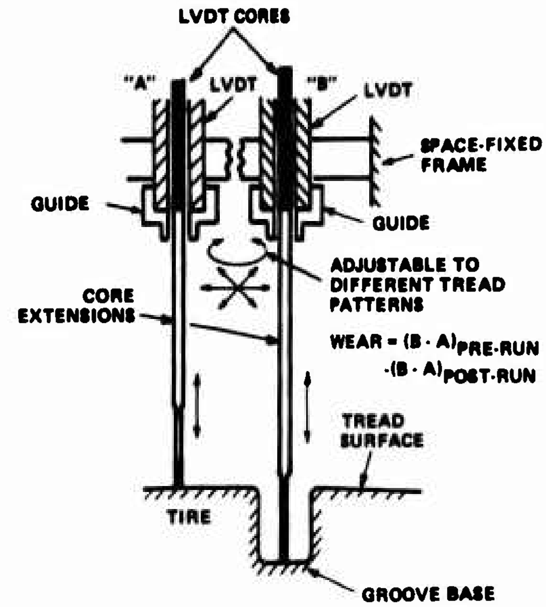


FIGURE 2

GEOMETRY OF LVDT WEAR MEASURING DEVICE

All tires had been pre-conditioned by operation on vehicles for 1600 miles. Tests were conducted at a load equal to 85% of the T & RA rated load at 24 psi inflation pressure and at a speed of 80 mph for a distance of 1000 miles. The relatively high speed reduced the machine operating time to 12½ hours. Tire tread surface temperatures were monitored continuously to insure that they did not exceed those experienced during typical road tests ($\leq 200^{o}$F). Replicate tests were performed on one high-mileage radial tire to ascertain repeatability of the wear data.

Roadway surface samples, Safety-Walk made by the 3M Company, were examined at intervals during the tests for rubber contamination and wear as all testing was deliberately constrained to one path on the TIRF belt surface. A scanning electron microscope (SEM) was used for sample analysis.

TREAD WEAR INSTRUMENTATION

A. Description

Tire tread wear rate was determined by the average change in tread depth which was measured after 1000 miles of the test cycle was completed on the tire. This measurement was made using an electromechanical transducer sensitive to linear displacements. Commonly known as a linear variable differential transformer (LVDT), this device, using auxiliary electronics, provides a d-c electrical signal that is directly proportional in magnitude to the imposed displacement. Direction of displacement, relative to a null reference, is indicated by the polarity of the output signal.

Calibration tests of the LVDT probes have demonstrated excellent linearity and stability. Using gage blocks to introduce known displacements, LVDT's having a range of ±0.5 inch, produced data with a standard deviation of less than 0.1 mil. Thus, 68% of all measurements would be expected to have a random error not exceeding one-tenth mil.

LVDT probes are used in pairs to perform tread-depth measurements with one probe in contact with the tread surface (rib) and the other in contact with the base of an adjacent groove. All measurements are made relative to a common reference external to the tire. Figure 2 illustrates the geometry of this device. Local tread loss is determined by taking a second set of measurements, following a wear test, with the probes set *exactly* at the same surface positions on the tire.

Wear measurements are facilitated using a frame structure that incorporates a horizontal spindle shaft to mount the tire/rim assembly and permit rotational positioning. The base assembly supports a fixture, above the tire, on which are mounted two pairs of LVDT probes and allows a gross positioning of the probes relative to the tire tread surface. Each pair of probes is mounted in a smaller fixture that permits (1) variation in the relative spacing between probes, (2) rotational adjustment of the entire dual-probe assembly and (3) vertical positioning of the probe-core assemblies. A general view of the apparatus is shown in Figure 3 while a

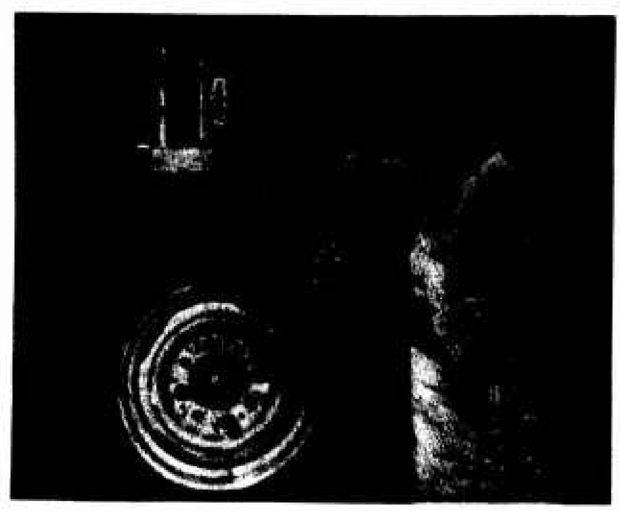


FIGURE 3

LVDT MECHANICAL PROBES IN CONTACT WITH TIRE

close-up picture of the core-probe assemblies in contact with a tire is shown in Figure 4. The advantage of using two pairs of probes is that simultaneous measurements can be made across the tread and along two meridians (by rotating the tire).

Electrical signals from each individual probe are fed directly into the TIRF computer where the necessary computations are made to arrive at a mean wear value based on all of the measurements. Computer printouts tabulate: (1) prerun and postrun tread depths at each location sampled, (2) tread depth changes, i.e. tread loss, at each location sampled and (3) the average wear.

B. Wear Measurement Locations on the Tire

Use of mechanical sensors to measure tread wear necessitates that pretest and post-test tread depth data be taken at precisely the same points on the tire surface. These fiducial points must be established on the tire surface and not with regard to an external (spatial) reference because of the viscoelastic properties of the tire. The following technique was used to assure correspondence between probing points in pretest and post-test measurements.

A small dot of color (made with a rubber-marking crayon) was located on the flat area of a groove base and one probe rod of the LVDT sensor was centered upon it. The other probe of the pair was then adjusted laterally/rotationally to contact a suitable point on the surface of a contiguous rib. For rib-type passenger car tires, interprobe spacing was typically 5/8 to 1 inch. The probe fixture permitted precise measurement of the angular and linear dispositions between these probes, relative to the fiducial dot, so that they could be exactly reproduced for repeat measurements.

Forty-eight measurements of tread depth were made on each tire for each test. This total was comprised of measurements made at each of six circumferential stations, approximately equally spaced, on each of four tire meridians and a complete set of replicate measurements made as the tire was rotated through one revolution. Shoulder areas of the tread were avoided in selecting wear locations as were rib edges subject to possible feathering. Figure 5 illustrates a tire footprint with the selected wear locations noted thereon.

Specific procedures employed in wear measurement are detailed below. First the tire tread surface was thoroughly cleaned, the tire was inflated to 24 psi and mounted in the test apparatus which was located in a temperature/humidity controlled area. Following tire temperature equilibration, wear locations were selected and marked in the manner described. The wear instrumentation was calibrated using a special fixture and tread depth measurements were made immediately at the 24 selected wear locations. The tire was

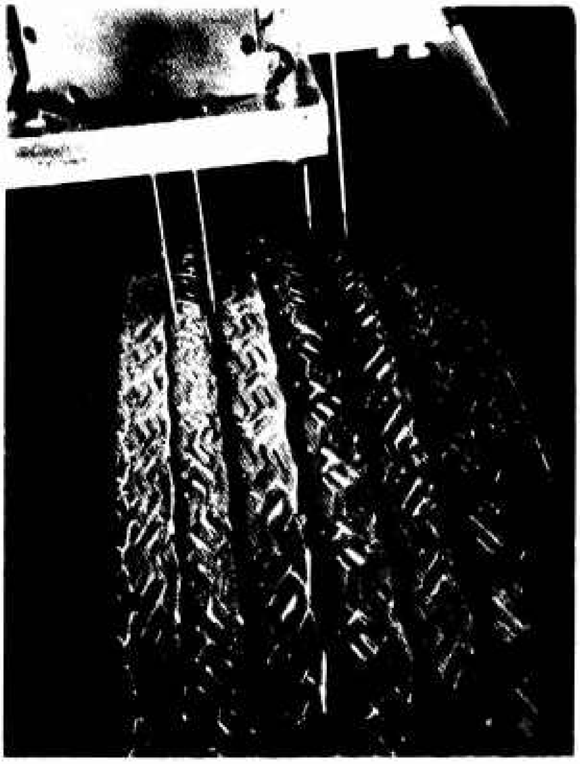


FIGURE 4

LVDT MECHANICAL PROBES IN CONTACT WITH TIRE

thereupon subjected to the wear cycle on the TIRF machine. Following completion of the wear test, the tire was reinstalled on the test apparatus and a minimum test period of four hours was allotted to eliminate tire creep, flat spotting and thermal gradients. The tire tread surface was again thoroughly cleaned using a bristle brush and an air flush. Tire pressure was checked to verify that there had been no loss of air. A second set of tread depth measurements was then made and the data were reduced to determine the mean tread loss during the test.

To quantitatively ascertain measurement repeatability with the tread depth sensors, tests were made at each of three conditions representing independent sources of random error: (a) the calibration of the sensors using gage blocks to provide known displacements, (b) tread depth measurements, at a given location on a tire, following a loosening/tightening of the rim on the test fixture studs and (c) tread depth measurements, at a given location on the tire, with the wheel turned through one revolution between successive measurements. Sample standard deviations (s), as determined from these tests are shown in Table III.

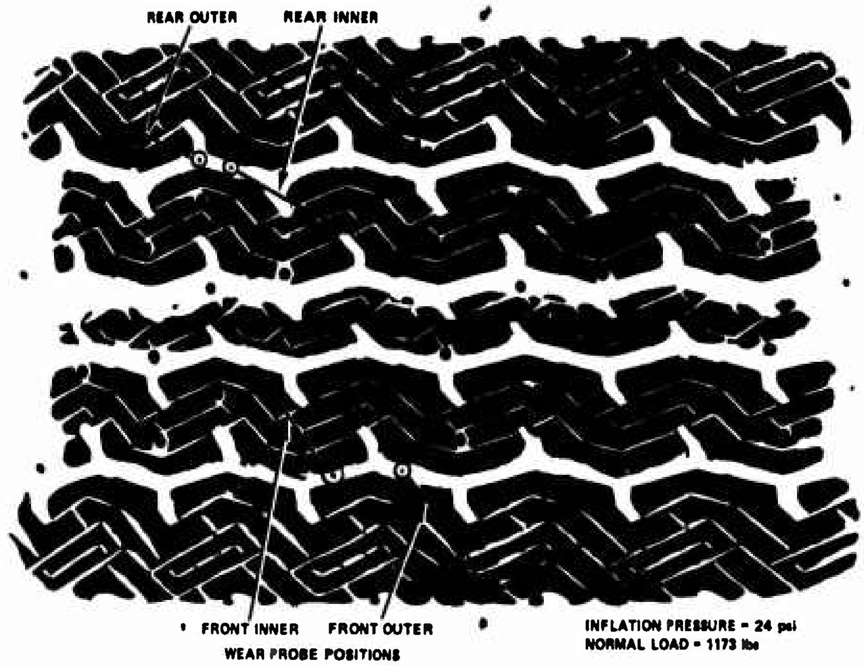


FIGURE 5 FOOTPRINT – DUNLOP HIGH MILEAGE RADIAL – #7-1-48

Table III - Repeatability of Wear Probe Measurements

Error Source	Wear Probe A	Wear Probe B
Calibration (gage blocks)	s=0.07 mil	s=0.085 mil
Loosened studs	s=0.82 mil	s=0.64 mil
Tire rotation	s=0.21 mil	s=0.31 mil
Composite	s=0.85 mil	s=0.72 mil

The largest random error was associated with loosening of the rim studs. A composite standard deviation for each probe was calculated as the root of the sum of the squares of each of the three error components.

WEAR TEST DETAILS

Tread wear is a strong function of slip as produced by applied steering angle and/or wheel torque. Several levels of wear severity are recognized and are expressed in Table IV in terms of mils per kilomile. In developing test procedures to achieve low-to-moderate wear rates, uniform cross-tread wear and surface textures representative of vehicle-worn tires, use was made of information developed on the TACOM program (2) related to the frequency distribution of slip angle and longitudinal slip, generated by passenger vehicles in typical urban/suburban/highway operation. From this information, it was judged that slip angles should not exceed 2° and longitudinal slip should not exceed 2½% if typical wear rates are to be achieved. Details pertinent to the selection of these limiting values are presented in Reference 5 and will not be discussed here.

Using one control tire and one high-mileage radial tire as test specimens, various cycles and random schedules of slip angle and torque were explored in order to define an acceptable wear schedule (i.e. one that met the stated objectives of wear rate and tread surface characteristics). All tests were made at a speed of 80 mph, a normal load of 1170 lbs., zero camber angle and a distance of 200 miles. Wear measurements were made after each 200-mile test segment. Mileage during this exploratory phase totalled 1800 miles (on both tires). As the result of these tests,

Table IV - Tread Wear Severity *

Low wear <10 mil/kmi (straight run)
Moderate wear 10-25 mil/kmi (0.2g cornering)
Severe wear 25-50 mil/kmi (0.3g cornering)
Very severe wear >50 mil/kmi (>0.3g cornering)

* Applicable principally to passenger car tires.

Table V - Tire Identification Schedule

TIRF Tire No.	Manufacturer	Size	Kind of Tire	Other Identification
7-1-48*	Dunlop	GR78-15	Radial (High-Mileage)	Elite Steel Radial
8-1-48	Dunlop	GR78-15	Radial (High-Mileage)	Elite Steel Radial
9-1-48	Dunlop	GR78-15	Radial (High-Mileage)	Elite Steel Radial
11-1-48	Armstrong	G78-15	Bias	4-Ply Polyester Control Tire
12-1-48	Armstrong	G78-15	Bias	4-Ply Polyester Control Tire
1-1-48	Cooper	G78-15	Bias (Low-Mileage)	Rapid, 4-Ply Polyester

* Replicate tests were performed on this tire.

the following schedule of slip angles and torques was determined as optimum and was therefore employed for all subsequent tests:

Slip Angles:

- Gaussian Random Variations; 0.3° rms
- Period of Randomness; 20 minutes

Longitudinal Slip (Torques):

- Sinusoidally Varying Torque; ±50 ft-lb peak
- Period of Sine Wave; 10 seconds

Tire operation on the Safety-Walk surfaced steel belt of the TIRF machine generally does not always produce a tread texture similar to that found on vehicle-worn tires. In contrast with the tactilely smooth surface of road-worn tires, following TIRF tests, rubber particles are found adhering to the tread surfaces which produce a tactile sense of coarseness and tackiness. To alleviate this problem, cornstarch (mean particle size of about 10 microns) was blown into the tire-roadway interface at a rate of about 23 lbs for a 1000-mile test or approximately 13 hours of operation. The use of cornstarch resulted in the smooth tread surface texture that was one of the program objectives.

In the early stages of the checkout tests, close visual scrutiny was maintained over the belt surface for possible buildup of rubber contamination. After one test of 200 miles, a sample of the Safety Walk was examined with a scanning electron microscope (SEM). No evidence of belt contamination or deterioration was found. This finding corroborated our previous experience (2) with tread wear testing.

The second phase of the test effort was devoted to the accumulation of wear data on six different tires subjected to the fixed-upon wear schedule of slip angle and torque. Table V identifies the tires. Prior to test, each tire was subjected to a 15-minute, 20-mile break-in. This break-in was necessary to permit the tire to become adjusted to the wear cycle. Prior tire operation had conditioned the tire and consequently a different tire set takes place when it is first subjected to the wear cycle. Such tire "memory" effects can result in an erroneous apparent wear, or even growth, if not compensated for by preconditioning. Pre-wear measurements were made subsequent to this break-in run but after a minimum four-hour tire soak in a temperature-controlled environment. All tread wear tests were 1000 miles in length and continuous in extent except as otherwise noted. Tread surface temperatures, as sensed with an infrared radiometer, varied between 98°F to 116°F for the tires shown in Table V which was well within the specified tolerance limit of 200°F.

TEST RESULTS

A summary of the numerical tread wear rates measured for the six test tires is shown in Table VI. The tread loss in mils per 1000 miles (kmi) was measured at a normal load of 1170 lbs (85% of T & RA rated load) at an inflation pressure of 24 psi. An examination of these data does indeed show that wear rate for the acknowledged low-mileage tire was indeed significantly larger than that for the high-mileage tires.

A chronology of the test events is important and instructive in an understanding of the results shown in Table VI. Firstly, the testing sequence occurred in accord with the serial listing in Table VI.

As verified by SEM photographs, the first specimen (tire #7-1-48) was tested on a substantially clean belt surface despite the fact that several hundred miles of checkout tests and the entire wear program of Reference 2 had been conducted on the same path of this first test, a road surface sample was removed for SBM examination. Since there had been no history of belt contamination by rubber during any previous wear tests, the test schedule was continued despite the unavailability of the SBM for immediate sample analysis. Visual inspection of the roadway surfaces was continued and no perceptible differences could be visually or tactilely discerned between the tire track area and other areas of the belt.

The remaining two high-mileage radials (#8-1-48 and #9-1-48) were tested in succession. Wear rate data for the three radials showed a decreasing trend; 9.23, 8.16 and 7.58 mils/kmi, respectively. Testing then continued on the two control tires (#11-1-48 and #12-1-48) with the 1000-mile test on the former being completed on a late work shift preceding a weekend. On the next work turn, testing began on tire #12-1-48. Upon reducing the data for tire #11-1-48, an apparently unrealistically low wear rate of 5.31 mils/kmi was obtained suggesting a change of roadway surface characteristics. Testing on tire #12-1-48 was immediately stopped. At this point in time 360 miles had already been accumulated.

A sample of the roadway surface in the tire track was removed and examined with the SEM. Severe loading with rubber was evident in this sample which had accumulated 4360 miles of testing since the initial SEM photograph. Figure 6 shows SEM photographs of the contaminated patch at two levels of magnification. Figure 7 shows similar loading apparently occurred during the time that the bias tires were being operated on the roadway.

Removal of rubber from the belt was accomplished by using a "scrubbing" tire. This operation involves mounting an available spare tire on the machine and subjecting it to a nominal normal load. With a roadway speed of 40 mph, the tire is manually steered to discrete angles of $\pm 5^{\circ}$. In approximately ten minutes of operation, the accumulated rubber was substantially removed.

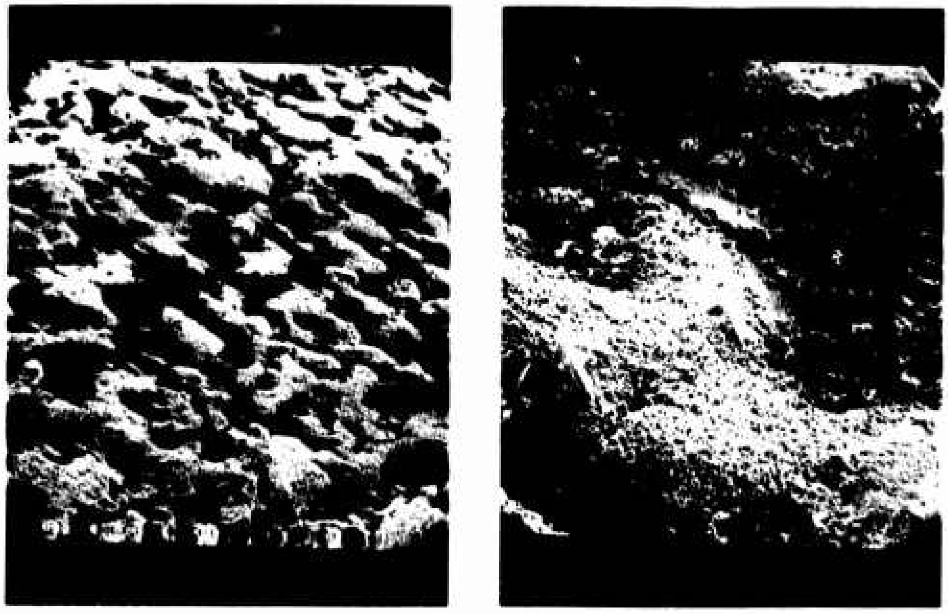
Upon resumption of testing, the TIRF machine was stopped after each two-hour period of operation to check for rubber contamination of the belt. If necessary, the test tire would be removed and replaced with the "scrubbing" tire and the cleaning operation performed.

Table VI - Summary of Tread Wear on Six Tires

Tire Identification	Shore Hardness	Wear Test Run	Average Wear mils/1000 mi.
Dunlop Hi-Mileage Radial #7-1-48	AVG = 61.3 s = 1.1	1000 mi.(1st)	9.23
Dunlop Hi-Mileage Radial #8-1-48	AVG = 62.3 s = 0.5	1000 mi.	8.16
Dunlop Hi-Mileage Radial #9-1-48	AVG = 61.3 s = 0.7	1000 mi.	7.58
Armstrong Control Bias #11-1-48	AVG = 55.3 s = 0.7	1000 mi.	5.31
Armstrong Control Bias #12-1-48	AVG = 57.7 s = 0.5	1000 mi.*	8.22**
Cooper Lo-Mileage Bias #1-1-48	AVG = 59.2 s = 1.3	1000 mi.	16.91
Dunlop Hi-Mileage Radial #7-1-48	AVG = 61.3 s = 1.1	1000 mi.(2nd)	8.57
Dunlop Hi-Mileage Radial #7-1-48	AVG = 61.3 s = 1.1	1000 mi.(3rd)	6.95

*First 360 mi on rubber-contaminated belt, final 640 mi on cleaned belt.

**A value of 9.86 is obtained by numerically correcting for first 360 mi (See Text)

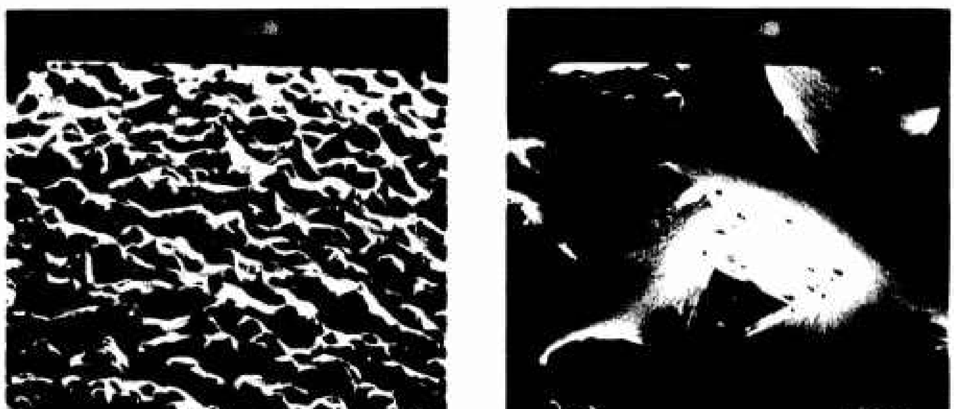


VIEW ANGLE - 45°
MAG. - 15X
ROADWAY DIRECTION OF TRAVEL →

VIEW ANGLE - 45°
MAG. - 100X
ROADWAY DIRECTION OF TRAVEL →

PATCH HISTORY: 4360 MILES RUNNING, TIRES #7, 8, 9, 11 AND PART OF #12

FIGURE 6 SEM ANALYSIS, CONTAMINATED ROADWAY SURFACE



VIEW ANGLE - 45°
MAG. - 13.2X

VIEW ANGLE - 45°
MAG. - 100X

PATCH HISTORY: BRAND NEW PATCH

FIGURE 7 SEM ANALYSIS, NEW ROADWAY SURFACE

The final 640 miles on tire #12-1-48 were accumulated on a clean belt surface. A composite wear rate of 8.22 mils/kmi (Table VI) was determined for this tire which had been operated on "loaded" and clean roadway surfaces. If it is assumed that the wear rate appropriate to the initial 360 miles is that determined for tire #11-1-48, then a wear rate of 9.86 mils/kmi can be attributed to the last 640 mils of wear tests performed on the clean roadway.

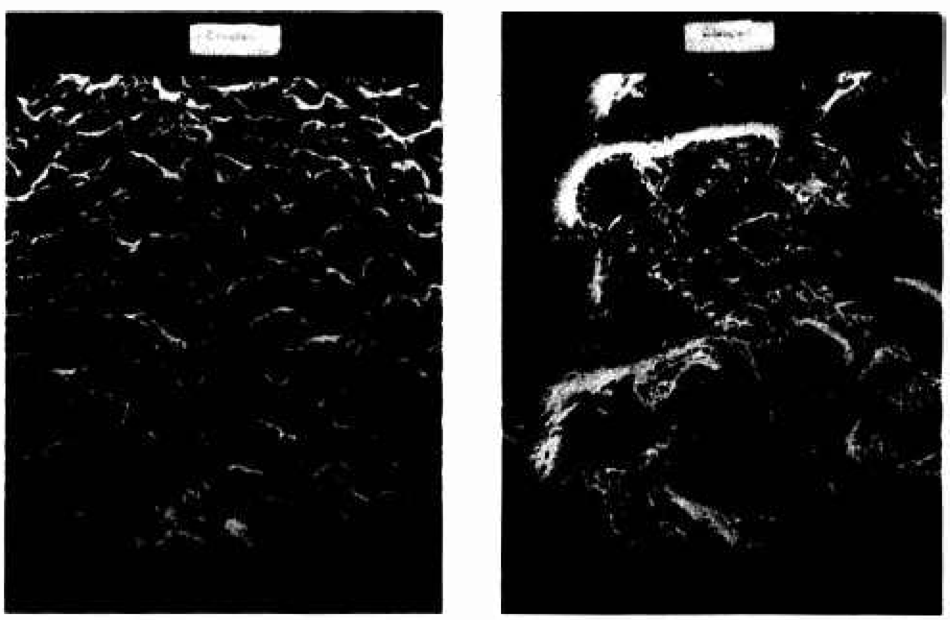
A wear rate of 16.91 mils/kmi was obtained from tests on the low-mileage bias tire. An examination of the meridional wear measurements indicated that this tire exhibited a higher asymmetry of cross-tread wear than any of the other tires. The front outer rib* wear was significantly larger than that of the other three ribs measured. This tire is believed to have experienced highly asymmetrical lateral forces which resulted in the non-uniform wear. Most of the tires tested exhibit some asymmetry of wear but of a much smaller degree. Average wear rates for the two frontal ribs were generally larger than those for the two rear ribs.

Two replicate test runs on a high-mileage radial tire (#7-1-48), which had been tested previously, concluded the program. This tire had been tested initially on a clean roadway surface for a continuous 1000 miles. Thus to make the data comparable, the replicate tests each were begun on a cleaned roadway and permitted to continue, uninterrupted for 1000 miles. A summary of the wear rate data collected on the respectively-tested high-mileage radial tire is given in Table VII below.

These wear data show a consistent decrease in wear rate with accumulated mileage. A reason for this trend cannot be reliably established based on the available information. It may be conjectured that this trend is an inherent characteristic of this tire. Another possibility may be progressive wear of the belt roadway surface with prolonged usage. Some SEM photographs which were taken near the completion of this program showed evidence of breakup of the individual asperities in the belt surface. Figure 8, a photograph of a sample which had experienced considerable usage, graphically illustrates a grit particle that has fractured and apparently lost a portion of its original bulk.

Table VII - Results of Replicate Wear Tests on Tire #7-1-48

Wear History	Wear Rate, mils/kmi
1st 1000 miles on TIRF	9.23
2nd 1000 miles on TIRF	8.57
3rd 1000 miles on TIRF	6.95



VIEW ANGLE = 45°
MAG. = 15X
ROADWAY DIRECTION OF TRAVEL →

VIEW ANGLE = 45°
MAG. = 100X
ROADWAY DIRECTION OF TRAVEL →

ROADWAY HISTORY: TESTS ON ALL SIX TIRES PLUS 2ND 1000 MILES ON TIRE #7-1-48, AFTER CLEANING

PATCH H

FIGURE 8 SEM ANALYSIS

*Viewing the tire as if it were mounted in the right front position of a vehicle.

Belt wear is a subject that requires further investigative study.

In summarizing the test results, the important conclusion is that TIRF-determined wear rate data do permit a gross rank ordering of the test tires according to the RMA selection of high, control and low-mileage radial tire shows the least wear, the bias (control) tire shows an intermediate level of wear and the low-mileage bias tire shows the largest wear rate by a factor of two relative to the radial tire.

Table VIII - Rank Order of Tires as Regards Wear Rate

Tire Description	Wear Rate, mils/kmi
High-mileage radial-Dunlop	8.25*
Control (bias) - Armstrong	9.86**
Low-mileage bias - Cooper	16.91

*Average of three tests on tire #7-1-48
**Calculated value

CONCLUSIONS

Based on the test results and the operational experience gained in executing this experimental study of a laboratory evaluation of tire tread wear rates, involving accumulated mileages of 5000 miles on high-mileage radial tires, 1000 miles on low-mileage bias tires and 2000 miles on control (bias) tires, the following conclusions are warranted:

- Gross rank ordering of tires as regards resistance to wear was demonstrated.
- A tire test technique for TIRF was developed that is capable of producing specified wear rates and tread surface textures resembling those of road-worn tires.
- Electromechanical tread-depth measuring instrumentation was demonstrated to be satisfactory in determining normal severity wear rates.
- Replicate tests showed consistently decreasing wear rates.
- Assymetrical cross-tread wear was experienced with the wear rate for the front half of the tire tread generally exceeding that of the rear half.
- Wear tests on the order of 1000 miles in length show potential in producing meaningful data on the TIRF machine.
- Rubber contamination of the roadway was experienced with the most rapid buildup occurring with bias ply tires.
- Mechanical means can be efficiently used to clean rubber-contaminated belt surfaces.

RECOMMENDATIONS

1. Related to future test operations:

   - Wear tests employing consistent lateral force variations rather than slip angle variations should be considered to attain more uniform wear across the tire tread surface.
   - Wear tests should impose consistent tractive force variations rather than wheel torque to achieve a uniform distribution in longitudinal tread wear.

2. Related to future studies directed to improvement of the laboratory technique:

   - Development of methods for detection and control/removal of rubber contamination during test operations.
   - Evaluation of Safety-Walk durability in terms of constancy of surface texture characteristics.
   - Identification and control of test conditions leading to variability in wear data.
   - Development and implementation of an improved wear-measuring device that provides significant improvement in the quality of the data and efficiency in measurement relative to the electromechanical device described herein.
   - Correlation of TIRF wear data with those obtained from controlled road tests and other test facilities.

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4. F. C. Brenner and A. Kondo, "Elements in the Road Evaluation of Tire Wear", Tire Science and Technology, Vol. 1, No. 1, 1973, pp 17-32.
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QUESTIONS AND ANSWERS

Q: Have you taken tires of the same manufacturers from the same batch and run repeated tests on them?
A: We did not do so on this particular program. We have another study underway on different kinds of tires. These are military vehicle type of tires but we don't have that much data from that effort that will help here.
Q: What maximum load range do we have over there?
A: Passenger car balance capability is 4,000 pounds.
Q: You indicated that the wear rate keeps dropping off, that it never reached a constant level. Does it eventually level off?
A: We don't know. There wasn't time to conduct any further tests to see whether the wear rate did in fact level off. I'm not quite sure but I think that the RMA had some road test data, which we were not privy to, that indicated that there was some decrease in wear rate with mileage for the road tests. It has been said about tires many times that as tires wear, their wear rates change. Generally wear rate decreases with wear. This is more pronounced for radial tires than for bias-ply tires. Again, we have not conducted such a test in this particular program and, to do it right, you have to continue this kind of test. The tire was run for 1,000 miles at a time and the wear was measured. Some three months later for another 1,000 miles. We'd like to continue that throughout the entire life of the tire and make those continuous measures.
Q: Did you check this tire for nonuniformities before testing and did you find any kind of relationships between the tire uniformity and wearing?
A: No, we did not make any checks in terms of any run-out, physical or geometrical distortions in a tire to begin with. One of the objectives of this program was to determine a method for short duration wear.We would take a new tire, which would have a minimum amount of break-in and running, and run it for a very short distance so that the wear would be very small. If you have nonuniformity in the tire it's reasonable to assume that it would wear non-uniformly, but if you think about the amount of variation you'd have around the tire in terms of its wear, when you're only wearing off five mils or so, the uniformity effect would be rather small. You'd only see it as you developed gross amounts of wear.
Q: What was the time lapse between each particular cycle of thousand miles and what was the temperature variation on the tires?
A: Well each tire generally was only tested once. Only the one tire was repetitively tested. Between the first and second test several weeks must have elapsed. Between the second and third thousand miles I'm not quite sure but the time interval was much shorter. There was a temperature limit given to us that the tire tread surface temperature should not exceed 200°F. We found on all these tests the tire temperature ranged between about 96° and 120°F. The tires ran rather cool for this test. These are surface temperature measurements not internal measurements. In terms of the time between measurements they varied. The shortest time we would permit would be four hours, because it was required to expose the tire to a four hour soak before all the creep and thermal stresses were stabilized and meaningful tread depth measurements made. Beyond that point, the time was not a great factor; it was a very small factor.

RELATIONSHIP BETWEEN FLAWS AND FAILURE IN PNEUMATIC TIRES AS IDENTIFIED BY ULTRASOUND AND ROAD TESTS

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A test was conducted to determine whether flaw characteristics found by reflection ultrasound correlate with tire performance during destructive testing. This work was done in conjunction with actual road tests to determine whether there is a correlation between tires destructively tested by roadwheel and those tested on the highway.

The test consisted of selecting a number of retread tires of known characteristics and pairing them in a way that will randomize any characteristics which might tend to confound the data. The tires were then inspected using the three nondestructive testing techniques known to have the most promise: (a) reflection ultrasound, (b) x-ray, (c) transmission ultrasound. After the inspection, the tires were then run on a roadwheel on a modified endurance test. Any failures were noted and compared with the results of the inspection.

A population of 109 tires was obtained for evaluation on both roadwheel test and road test. The split was 75 tires to road test and 34 tires to roadwheel test. In order to assume a random selection for both road and wheel test, the tires were broken down according to major construction categories: bias, fabric belted, glass belted, radial cold cap, and radial hot cap. Tires for the wheel test were selected proportionally from each of these groups with approximately one-third of each major category going to wheel test and the balance to road test.

Of the 34 tires in the wheel test, ultrasound identified ten as having significant damage either before or after retreading, of which six failed during the wheel test. The other four tires showing damage were analyzed and showed damage of sufficient variety to warrant consideration as a failure.

AUTOMATIC ANALYSIS OF HOLOGRAPHIC INTERFEROGRAMS

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INTRODUCTION:

Holographic Non-Destructive Testing (HNDT) has proved to be a useful technique for testing tires. Internal ply separations, voids, low adhesion levels, non-uniformity, multiple cord fractures, carcass to belt damage, foreign object contamination, and mold pinch are some of the tire defects that have been identified using HNDT. The usefulness of such data has led to an increased use of and dependence on HNDT for critical testing applications. Indeed, some airlines now require all of their retreaded tires to be inspected using HNDT.

This increased dependence on HNDT has created problems related to the gathering, analyzing, recording, and storing of the data. It has been clear to users for some time that if HNDT is to be a viable tool that can be used in a production environment, then some type of computer assistance will be required in gathering and analyzing the data.

This paper describes the progress that has been made at Industrial Holographics, Inc. to provide computer assistance to gathering, recording, and analyzing HNDT data.

FIGURE 1
I.H.I. COMPUTER CONTROLLED TV VIEWING STATION

DATA HANDLING AND RECORDING AIDS:

With several hundred tires per day being tested on some holographic tire testing machines, the handling and storing of the holograms quickly becomes a critical task. The ability to identify a particular hologram without having to view the reconstructed image can greatly ease the handling of the holograms. The newest holographic interferometers used in the IHI tire testing machines include the capability of automatically writing an identification number on the film. This identification number is automatically incremented for each new tire. Under computer control, several different holograms at varying vacuum levels can be recorded automatically for each sector of the tire. The vacuum level and sector number are automatically written on each frame of the film for easy identification.

In order to analyze the data and document the results, the hologram is inserted in a TV viewing system that displays the fringe pattern on a video monitor. A photograph of this computer controlled viewing system is shown in Fig. 1. The location of defects in the tire can be pinpointed by superimposing a grid pattern on the fringe system with the grid lines separated circumferentially by 15°, as shown in Fig. 2. The proper grid lines for different sectors can be displayed by pressing the sector number on the keyboard. The number of sectors per tire can be set to 2, 3, 4, or 6 depending upon the number of frames made during the test. This TV grid system eliminates the need to grid the individual tires. Only a single reference mark in the center of the first sector needs to be put in each tire.

The keyboard can be used to type any alphanumeric data on the screen. Full editing capability is provided–including insertions and deletions. Special symbols can be used to identify separations (*), non-uniformities (~), low adhesion regions (@), and bad splice areas (/, \). An example is shown in Fig. 3. A permanent hard copy record of this image can be made with a Polaroid camera, as shown in Fig. 4. Alternatively, one can output the alphanumeric data

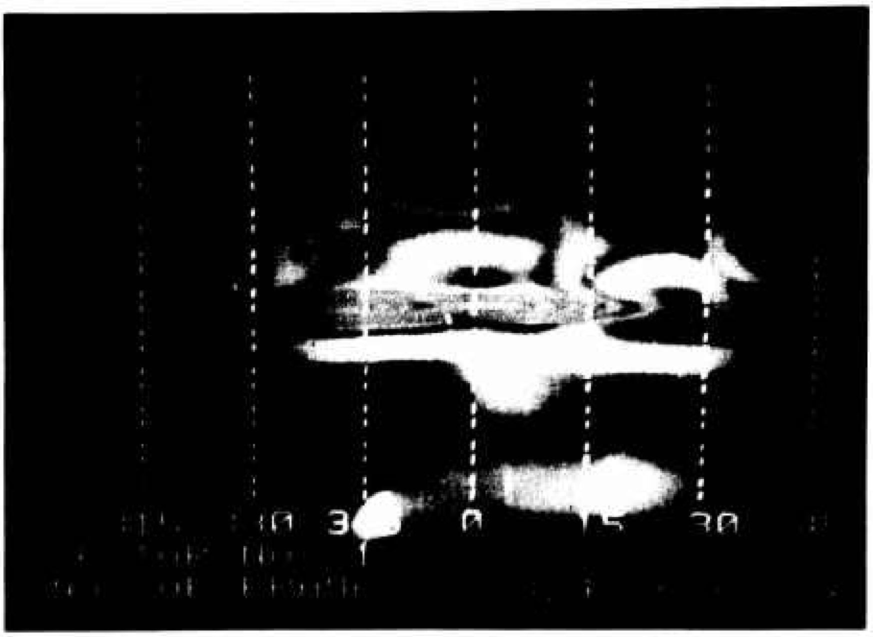

FIGURE 2
VIDEO MONITOR DISPLAY OF FRINGE PATTERN WITH SUPERIMPOSED GRID LINES

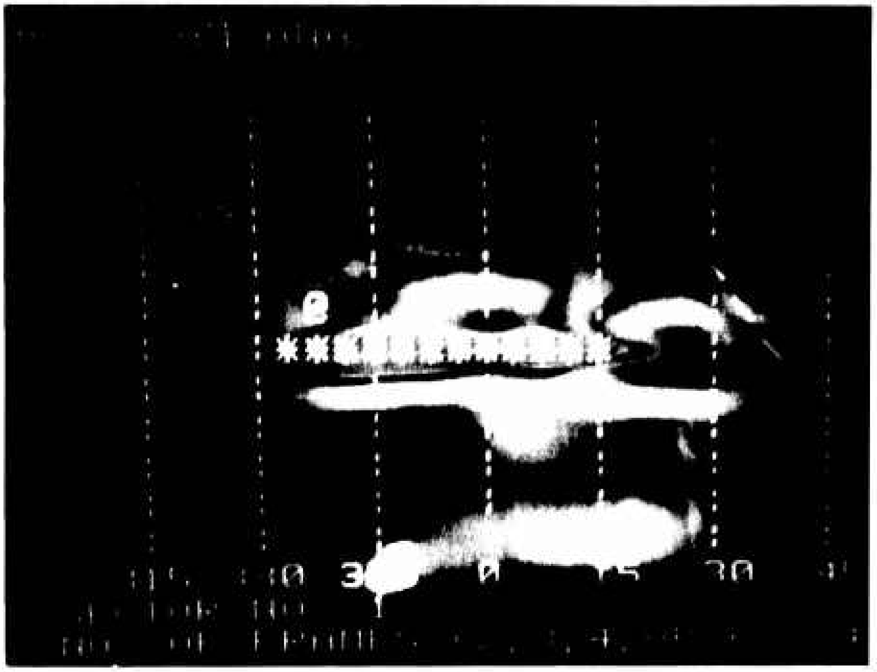

FIGURE 3
THE HOLOGRAM IMAGE CAN BE ANALYZED BY
TYPING SPECIAL DEFECT SYMBOLS ON THE VIDEO MONITOR.

FIGURE 4
RECORDING THE IMAGE ON THE VIDEO MONITOR WITH A POLAROID CAMERA.

and grid lines to a printer to give a permanent charting of the hologram, as shown in Fig. 5. The special defect characters (*, ~, ", /, \) can be printed in red for emphasis and ease in reading the charts.

The system described above greatly simplifies the task of reading, interpreting and documenting holographic interferograms. However, this task must be carried out by a skilled person who is trained to recognize tire defects associated with fringe anomalies. It is clear that if HNDT is to be used on a widespread basis in a production line environment, then some type of computer assistance in the actual analysis of the holographic fringe pattern will be necessary.

image. The totality of possible measurement vectors defines a feature space in which the classifier operates.

A wide variety of features can be extracted in the preprocessing stage. However, there are certain desirable characteristics of features that are likely to prove useful in HNDT. These include 1) vacuum independence, 2) ease of computation, 3) spatial and size independence, 4) good class discrimination, and 5) proper scaling and normalization.

Once a feature vector has been defined, the classifier/trainer block in Fig. 6 uses the feature vector either to

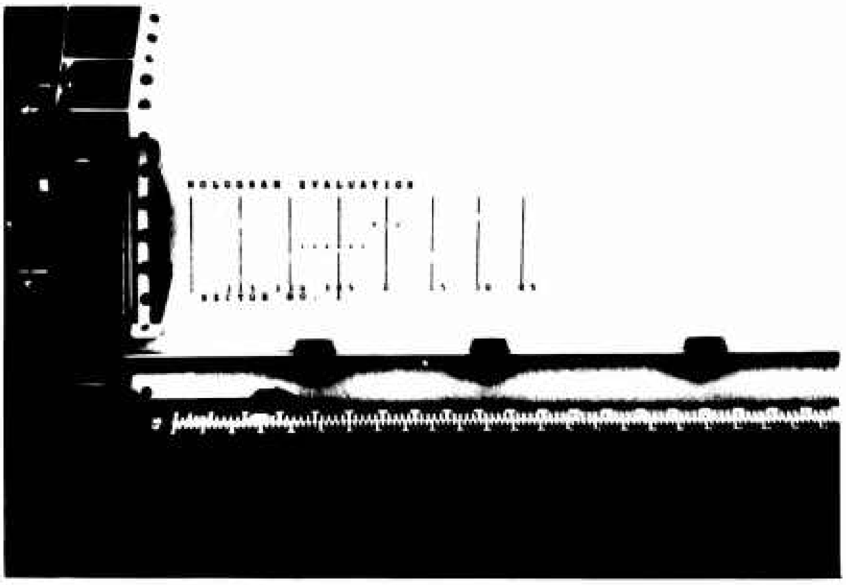

FIGURE 5
THE HOLOGRAM EVALUATION CAN BE PRINTED BY THE COMPUTER ONTO A HARD COPY OUTPUT DEVICE.

COMPUTER ANALYSIS OF HOLOGRAPHIC FRINGE PATTERNS:

Two applications of computer analysis of holographic fringe patterns are likely to prove useful in HNDT. One application will be to simply accept or reject a tire. A second application will be to flag suspicious tires for further detailed interpretation by trained personnel.

The system shown in Fig. 1 has the capability of scanning the holographic fringe pattern and storing the digital data in the computer memory. A block diagram of a pattern recognition system that can be used to analyze the holographic data is shown in Fig. 6. The scanned video data is fed to a preprocessing block in which certain features of the fringe pattern are extracted. These features form a measurement vector x which characterizes a particular

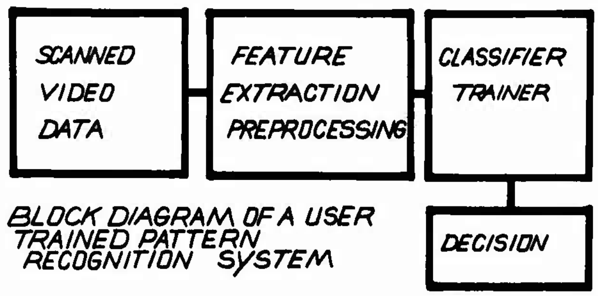

FIGURE 6

identify an unknown measurement (classify) based on previous experience, or to help add to its experience (train). The classifier, based on its experience, associates every region of its feature space with a particular class (e.g., accept, reject, unknown). A decision is then based on which region of the feature space a particular measurement vector occupies. There are a variety of training and classification algorithms that could be used in the classifier/trainer stage. However, for HNDT the desirable characteristics of a classifier include 1) nonparametric, 2) real time capabilities, 3) interactive, 4) trainable over time, 5) capable of operating with a limited sample set, and 6) ease of operation. Our experience has shown that it is possible to achieve most of these characteristics in a single classifier.

SUMMARY:

In order for HNDT to play a central role in tire testing, some type of computer aid for handling, recording and analyzing the data is necessary. This paper has described a system that is being developed at I.H.I. that takes a major step in this direction. The basis of the system is a TV viewing station that displays the holographic fringe system on a video monitor. The system can be expanded by adding a microcomputer and keyboard that allows an operator to superimpose a grid pattern and any other alphanumeric data on the screen. Hard copies can be made on Polaroid film or a printer. The complete screen data can be stored on video tape. Alternatively, the charted information about each hologram can be stored on a floppy disk for later retrieval.

The fringe data can be scanned, and from computed features the computer will either classify the hologram, or, at the option of the operator, use the measurement as training data for future classifications. Initial experience gained in using the system indicates that it is a useful aid to the human interpreter and a promising tool for relieving the human operator of actual decision making.

COMMENTS UPON THE PAST, PRESENT AND FUTURE OF HOLOGRAPHIC NDT OF PNEUMATIC TIRES

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For those of you who are not familiar with holography, I would like to begin by introducing you to the basic principles and how we, at I.H.I., incorporate them into a double exposure holographic interferometer which is used in our tire test equipment.

Simply stated, holography is a process of three-dimensional photography. Figure 1 graphically shows the setup to record an image in a photographic media that can be displayed in three dimensions. A coherent or single frequency light is used. As shown in the figure, a laser is used for this single frequency light and it is split into two distinct paths—one path, called the object beam, is used to illuminate the object and is reflected back to the film plane; the second path, called the reference beam, is brought directly onto the film plane. It is the interference of the reflected light wave coming from the object and the light wave from the reference beam that creates an interference pattern that is recorded on the film. When the film is illuminated by a source similar to the original reference beam, the object will be reconstructed in three dimensions. Figure 2 demonstrates this reconstruction.

By using a double exposure holographic technique, an interferometer can be constructed to measure very small movements of the object when it is stressed. Figure 3 demonstrates this basic principle. If the object is holographed when it is at a steady state condition, and a second hologram is taken on the same film frame after the object is stressed to that shown by the dotted line, this small movement will change the length of the reflected light path. The difference in optional path length creates a series of interference fringe lines as shown. Since the object has moved uniformly toward the film plane, the interference fringes are horizontal and uniform.

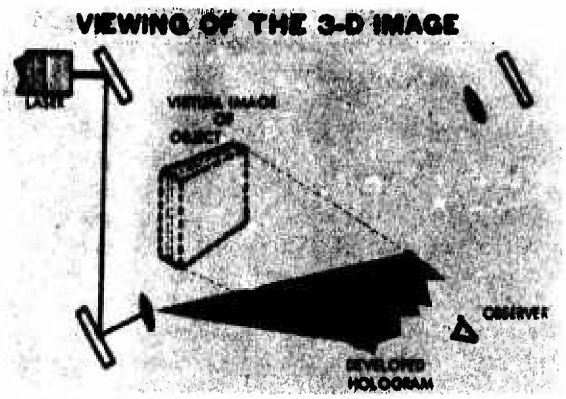

FIGURE 2

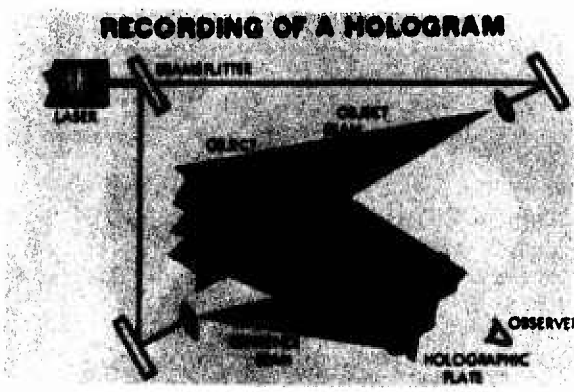

FIGURE 1

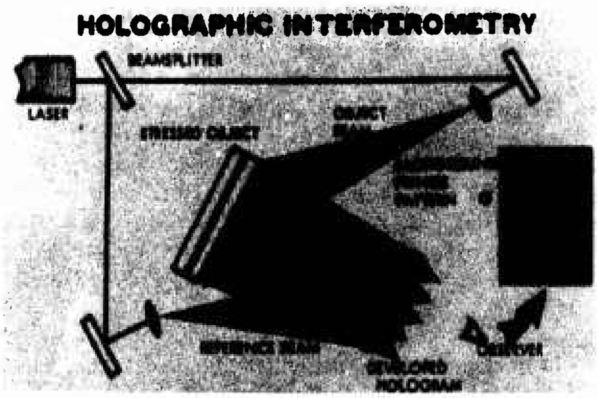

FIGURE 3

Let us consider a tire with a ply structure and a void between the plies as seen in Figure 4. We use the same procedure again and take a hologram of the tire at atmospheric pressure. We stress the tire by introducing a vacuum around it. The vacuum creates a bulge at the area of the separation. If we take a second hologram superimposed over the original hologram, the fringe lines would be distorted in the area of this bulge. In fact, a topographical map of the bulge would be created in this localized area while the background fringes in the areas of uniform stress would still be horizontal and uniform. Any condition within the structure of a tire that creates a non-uniform stress such as fatigue, separations, non-uniformity in the construction, low adhesion, overlapping of splices, and uneven cord tensioning will have a distinct holographic fringe pattern. It is these basic principles and the procedures that are used in our holographic tire test equipment.

FIGURE 4

Figure 5 shows the original holographic tire test equipment built by G.C.O. I will start with this original equipment and discuss how this basic design has been expanded and improved over the years. Originally, the laser was mounted in back of the test platform which was rather inefficiently isolated from vibrations. Through a series of mirrors, the laser light was brought around from the back and into the camera which is located at the center of a rotating table. The tire was placed over the camera and rotated around it. These old units used a helium-neon laser which was low in power and had a considerable light loss within the system. As a result, long shutter opening times (3 to 5 seconds) were necessary which made the total system sensitive to vibration and outside interference. The coherence length of the light was short, therefore limiting the size of the tire that could be inspected. The electronic controls of this unit were old style vacuum tubes and magnetic relays. High voltage contacts and the like made the entire electrical system less than trouble-free. In spite of all these adverse characteristics, there are still a number of these machines performing daily tire inspection at locations around the world. Some are still in their original condition and some have been modernized and updated.

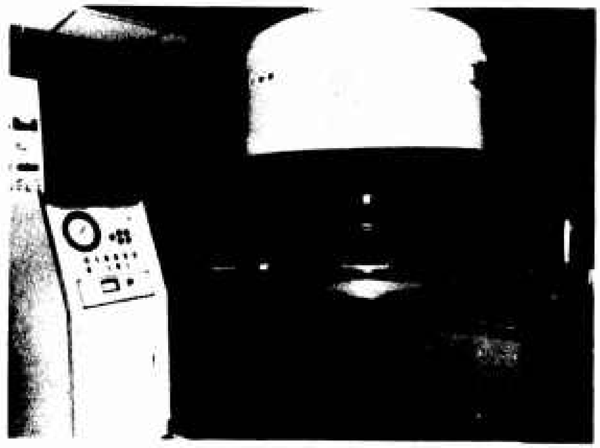

FIGURE 5
G.C.O. MACHINE

The K60 unit shown here in Figure 6 was the first attempt. The test platform is changed to mount the laser pointing directly into the camera. The dome size was increased. A Krypton-ion laser was introduced to give a higher power, longer coherence length, single frequency light, thus reducing shutter opening times. A new pneumatic mount system was introduced to reduce vibration effects.

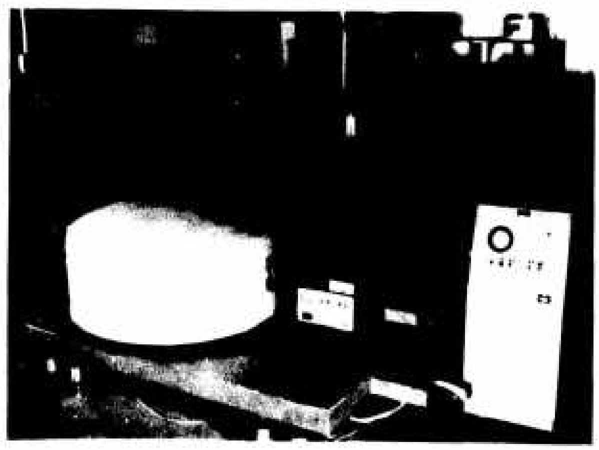

FIGURE 6
I.H.I. MODEL K60

A third generation machine, the Industrial Holographics Model K160, shown in Figure 7, was the first holographic test unit to be placed in on-line production situations. This unit has been, and still is, the primary unit being used to inspect retreaded high speed aircraft tires. While this unit is somewhat similar in appearance, there are some significant differences to be noted. The system uses special heavy

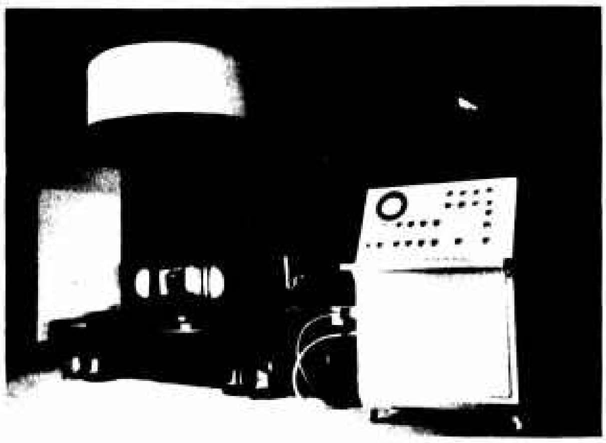

FIGURE 7
I.H.I. MODEL K160

industrial environments. As before, a Krypton-Ion laser is positioned so that the incoming light enters directly into the camera optics. A new laser cradle mount system is employed for ease of alignment. The Krypton-ion laser uses an oven heated etalon for a high power, stable single frequency light with long coherence lengths. Shutter speeds are reduced to less than one-tenth of a second The dome lift mechanism has been changed to a high speed pneumatic unit. The turntable drive unit is changed to a gear drive system which allows for fast, precise positioning of the tire during rotation. Another major advance in this generation machine was the introduction of a conventional, commercial, solid state controller using Allen-Bradley logic cards for sequence control. Figure 8 shows the back of the controller with the rack of control logic cards, which are throwaway type boards available from any Allen-Bradley supplier. In addition, precise timing delays have been introduced through the use of thumb wheel timers shown here on the left.

The overall enhancements and goals in the design of this machine were to achieve a reliable unit which could be operated as an on-line inspection device in moderate volume production facilities, and also as a research and development tool or Q.C. sampling tool. These goals have been achieved and this unit is still used as a standard holographic tire test unit being sold around the world.

This same basic machine has been scaled up to our Model K172/194, see Figure 9, which is a dual purpose machine that is the same as the K160–only with a 72 inch dome. The second configuration is for testing small earthmover tires up to 92 inches in diameter.

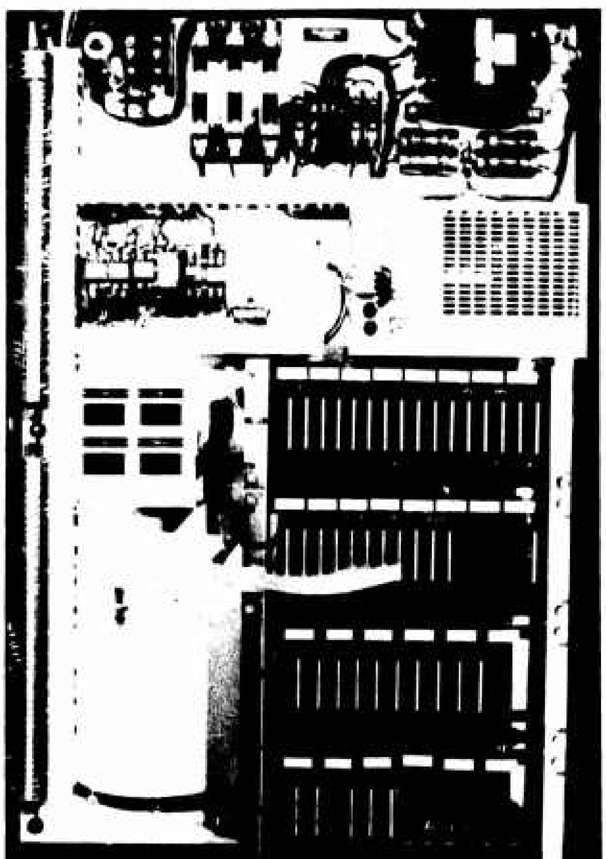

FIGURE 8
ALLEN-BRADLEY SOLID STATE CONTROL PANEL

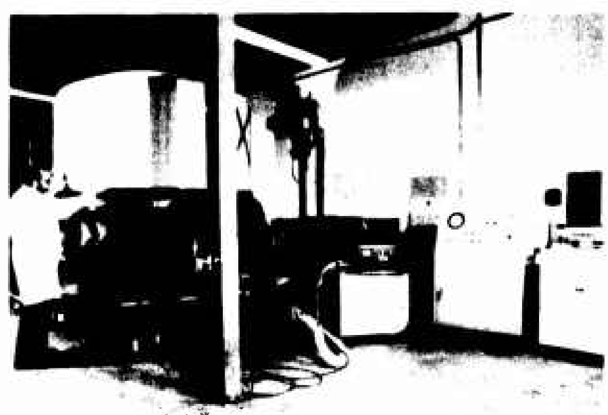

FIGURE 9
I.H.I. MODEL K172/194

A fourth generation of machines is currently in production. Using some of the basic concepts of the K160, a new high speed production unit, designated our Model K248, (see Figure 10), has been designed and produced to meet high volume requirements. Along with available automatic film

FIGURE 10
I.H.I. MODEL K248

processing, this unit is designed to test more than one thousand (1,000) tires per 24 hour period. As can be seen, this unit is a dual-domed unit with two test positions. The unit is redundant from a systems standpoint in that it has two on-board lasers, two vacuum cabinets, and each dome is capable of being cycled independent of the other. This redundancy was purposely introduced into the design to insure overall reliability and continued operation in a high production environment. While some of the basic principles of the K160 have remained, a major change in this unit has been the introduction of a microcomputer controller which has built-in automatic sequences and reduces operator skills to a minimum. The operating functions of the machine are displayed on a video monitor, as shown in Figure 11. The operator can key in machine settings such as film exposure, vacuum level, number of photographs in the film canisters and identification serial numbers, by using the keyboard below the screen. During machine operation, the lower portion of the screen flashes machine sequence messages and instructions to the operator. This information can also be used for diagnostic information that can be useful in trouble-shooting the machine.

This microcomputer incorporates new features which are not available on the standard K160. One of these features is the capability of writing information onto the firm. For instance, digital information can be entered at the start of a new roll of film which can act as a permanent identification. During the production run, identification numbers can be entered for each tire with this identification only having to be entered for the first tire. The machine automatically increments the identification code by one (1) every time a tire is run. When the film is developed, each tire's set of holograms has its own identification number.

Another unique feature of this machine is the capability of automatically adjusting the beam ratio. This feature allows running "black" tires without painting or talcing. The beam ratio is automatically set for each tire that is placed in the machine regardless of color.

Another feature is the capability of running a calibration run totally automatic. The operator keys in a shutter setting range and a beam ratio range on the microcomputer. The machine will then automatically cycle through the vari-

FIGURE 11
I.H.I. MICROCOMPUTER
CONTROL CONSOLE

ous shutter settings and beam ratios. The shutter and beam ratio information is printed on the film, see Figure 12. After developing, the operator merely selects the optimum setting selected from the calibration run. He uses this optimum setting as an input to his exposure setting at the top of the screen. Once this setting is introduced into the computer, the computer will use this shutter setting and automatically adjust the beam ratio to obtain the selected beam ratio. This capability of adjusting beam ratio for each individual tire ensures that the optimum value is used and is totally independent of the inside tire color.

Another desirable feature that has been incorporated into the computer is an automatic series of vacuum level changes for each sector being tested. The operator can enter a lower and upper vacuum level and an increment. The computer will start at the lower vacuum level and will increment up by the specified increment until it reaches the upper vacuum level. This sequence will be shot for each sector, as shown in Figure 13. (NOTE: The vacuum is printed as the first two digits of the identification number.) A full series of vacuum levels will be run on all sectors depending upon the number of sectors that are selected. This feature can be extremely desirable for tire development and research purposes and heavy duty tires.

A fifth generation design is being incorporated into a machine for the inspection of O.T.R. tires. These are the huge, expensive tires used on today's earthmoving equipment. We are currently in production of a machine capable of testing a tire up to 130 inches in diameter with a maximum weight of 6000 pounds. This unit incorporates the Model K248's latest technology of using the microcomputer control unit. It has two cameras which will have horizontal and vertical movement. These cameras are capable of being positioned with different views of the tire to simultaneously collect information anywhere within the bead-to-bead region of the tire. This machine will be installed as an on-line inspection tool in a major new tire manufacturer's earthmover tire plant.

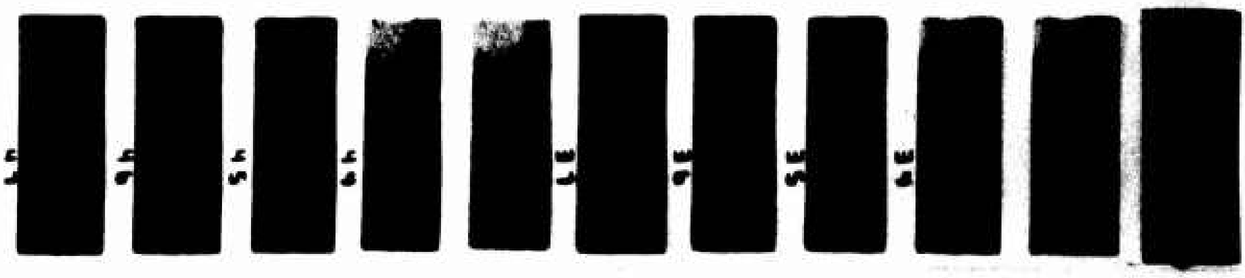

FIGURE 12
CALIBRATION RUN

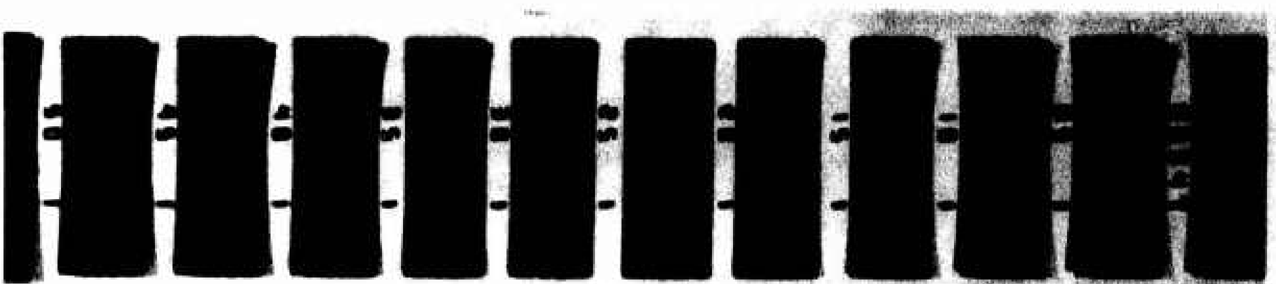

FIGURE 13
MULTIPLE VACUUM RUN

One other area of primary interest has been the development of an automatic computer scan of holographic data generated by our tire analyzers. We currently have hardware available which will be the subject matter of Dr. Haskell's talk. Along with the computer analysis of the holographic data, our long-term corporate objectives have been to design and develop a machine with a reliable, reusable, real time imaging system with an on-board computer for analysis of the image. The operator will not be required to analyze the data. All decisions for "accept or reject" will be made by the on-board computer.

Our current corporate research and development programs are aimed in the direction of developing machines with these capabilities, and our ultimate objective is inspecting a passenger tire for the cost of a quarter. We believe that we are well on the way to achieve these goals, thereby making holographic tire inspection a viable, on-line production tool for inspecting every passenger tire coming off the production line.

FAILURE ANALYSIS OF AIRCRAFT TIRES AS OBSERVED BY HOLOGRAPHY

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ABSTRACT

A review will be given of recent methods employed in the holographic non-destructive testing of aircraft tires. Comments will be made on both equipment and procedures. The prime purpose of this paper will be to answer the basic question: Do separations propagate? Dozens of specific examples of the propagation of separation in aircraft tires are presented. Test results are presented on over two thousand tires. Consequently, based on our observations, separations always propagate; many at a very fast rate. Detailed documentation of individual cases of separation propagation is provided.

This paper summarizes a study carried out on the subject of failure analysis of aircraft tires as observed by holography.

Much of the work we have been doing on aircraft tires is extremely preliminary. We have treated only a few thousand to date. Normally our testing facility tests about 20 to 40 tires per day. We have learned from truck tire testing in past years, that it takes a very large data base over an extended period of time before one can establish with any degree of credibility exactly what is taking place in terms of specific failure mechanisms. Our basic objective is an understanding of the life expectancy or durability of a tire. How does one get his money's worth out of a tire? How, basically, does it fail, and when is it going to fail? In the case of truck tires, we look at the diameter of a given separation in a tire as a function of the mileage. We follow a given tire up to 160,000 miles. For example, a quarter inch wide separation in a new radial truck tire will grow linearly as a function of mileage up to typically one or more inches within 100,000 miles. We plot the separation diameter as a function of mileage through repeated tests at various mileage points. We then observe the size of the separation just prior to the failure point. We note, within the limits of statistical error, that in general there is a linear relationship between separation size and mileage, which almost always results in separation propagation which is quite predictable in other tires of identical construction under similar road and load conditions.

Now let us return to our discussion of aircraft tires. Aircraft studies are much more difficult. The initial sample of a given size of new R-0 tires typically have few separations in them, 1% or 2% on the average, 3% or 4% at the most. However, after watching them beyond R-1, the first recap level, or R-2, the second recap, we will sometimes see separations suddenly appear along with a progression of poor structural uniformity in the tire. Separation will propagate at a fairly slow rate for a period of time, and then suddenly propagate almost exponentially into a quick and sudden failure. Instead of having the linear separation propagation relationship which we observe in the case of a typical truck tire with good uniform strength, we will have a situation where we may see relatively slow propagation of separation over an extended period of time which then abruptly leads into sudden separation growth as the number of landings proceed. In a typical aircraft tire, we will see a small separation sit idly by, propagating very slowly as the number of landings progress, then all of a sudden it will propagate to failure over a relatively short number of landings. Aircraft tires are complex because the propagation mechanism is critically influenced by the overall structural strength and structural uniformity of the carcass. That is, a small separation in a weak carcass may propagate very fast, but a moderately sized separation in a very strong carcass will propagate very slowly and go through a surprising number of R levels before it will lead to a terminal failure.

The result in aircraft tires is that the stretch or the elongation as a function of applied load which gives us the most significant data, as opposed to the classical mechanics case for homogeneous metals where strain data which is measured as a function of applied stress, provides us with the best information. Life is basically simple in a homogeneous metallurgical situation, a one dimensional problem where you can pull on the material with a given applied stress in pounds per square inch and measure out the corresponding strain in inches per inch. Holography testing does not provide us with strain data directly, but rather gives us the overall stretch or elongation characteristics of the carcass for a given applied load. This type of data turns out to be exactly what we need, since it reveals the general strength characteristics of the tire.

Briefly, we might note that holography is a laser photographic process which can photographically record a three dimensional view of the tire. Employing as a test method the combination of holography and interferometry, minute displacements can be measured in three dimensional objects. In the case of a tire system, it is absolutely essential to look at the complete three dimensional object, rather

than gathering data at a single point which is the typical case for metals. In a tire, the comparison between relative rather than absolute data points is crucial to the strength of materials analysis. The measurement of minute displacements in tires as a result of an applied load can lead to judgments about the quality of the tire.

Let us look at the following simple analogy which will help us to understand the manner in which we obtain the final data. Suppose we had a thinly stretched rubber membrane of which we had taken a three dimensional hologram. (A hologram is a special type of photograph taken with a laser beam.) We could then set up a very simple interferometer and look at that membrane and push it very gently forward. The image we would see as we push that membrane out would consist of rings or concentric circles which would be contours of constant displacement. As we push the membrane out, we could then generate a contour map (the contour lines on the map would represent levels of constant displacement or levels of constant height above a reference) which would tell us the general displacement from the original position. Now in terms of a tire, we want to see the overall displacement between the unstressed and stressed tire carcass. In reality, what we are trying to do is just set

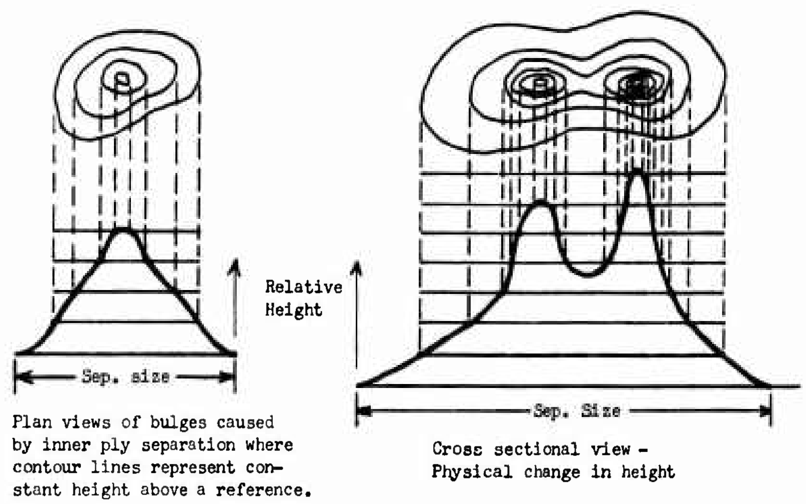


FIGURE 1A
Interferometric Contour Maps

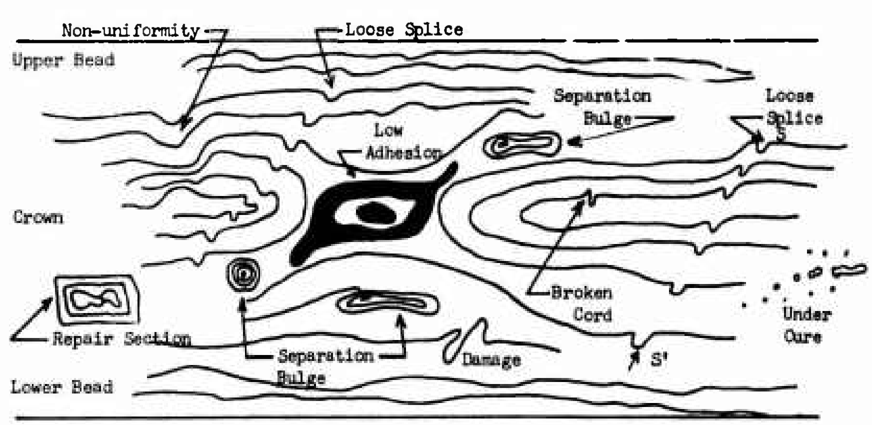


FIGURE 1B
Topographical Map of Typical Low Quality Aircraft Tire After Numerous Retreads

up a three dimensional stress-strain measurement where we can read the relative stretch or displacement out in the form of a simple image as a result of an applied stress. It is of crucial importance that we obtain our data over a region of the tire's surface as opposed to obtaining data at a single point in space which was the case prior to holographic interferometry. In a holographic tire testing machine, we take a photograph or a hologram of an interior region of a tire, say for example, a left to right view from 0 to 90 and a top to bottom view covering the tire from the top head to the bottom head as viewed from the center of the tire after we have applied a stress, which can be done by putting the tire in a vacuum, we come up with a contour map that represents to us the stretch that is produced in the tire as a result of the applied stress (note Figure 1).

To get the tire ready for testing, metal spreaders are put into the interior to hold the beads far enough apart to enable the camera to view the interior of the tire (note Figure 2). The tire is then ready to be placed into the holographic machine on a merry-go-round turntable assembly under a vacuum dome. The tire surrounds the interferometric camera which takes the hologram. Ninety (90) to 120 circumferential degrees are automatically viewed at a time. The tire is holographed (or photographed) both with and without an applied vacuum to obtain the relative stretch caused by the applied stress. The tire is then rotated to the next 90 or 120 degree view, etc. Typical test time for a tire for the type of results we will be discussing is about two minutes (note Figure 3).

In most tires which we test, we obtain an upper mid-sidewall to lower mid-sidewall view. In a few cases, we insert mirror assemblies to provide bead-toe- to bead-toe views, as shown in Figure 4.

Now let us come back very briefly to the method. If you were to take an object and put it in a vacuum, that object being a multiple ply tire, the overall tire being tested would dilate, stretch, or elongate as a result of the applied vacuum. Our camera would record a background fringe pattern which would relate to us how the tire surface moves or stretches topographically (reference Figure 1).

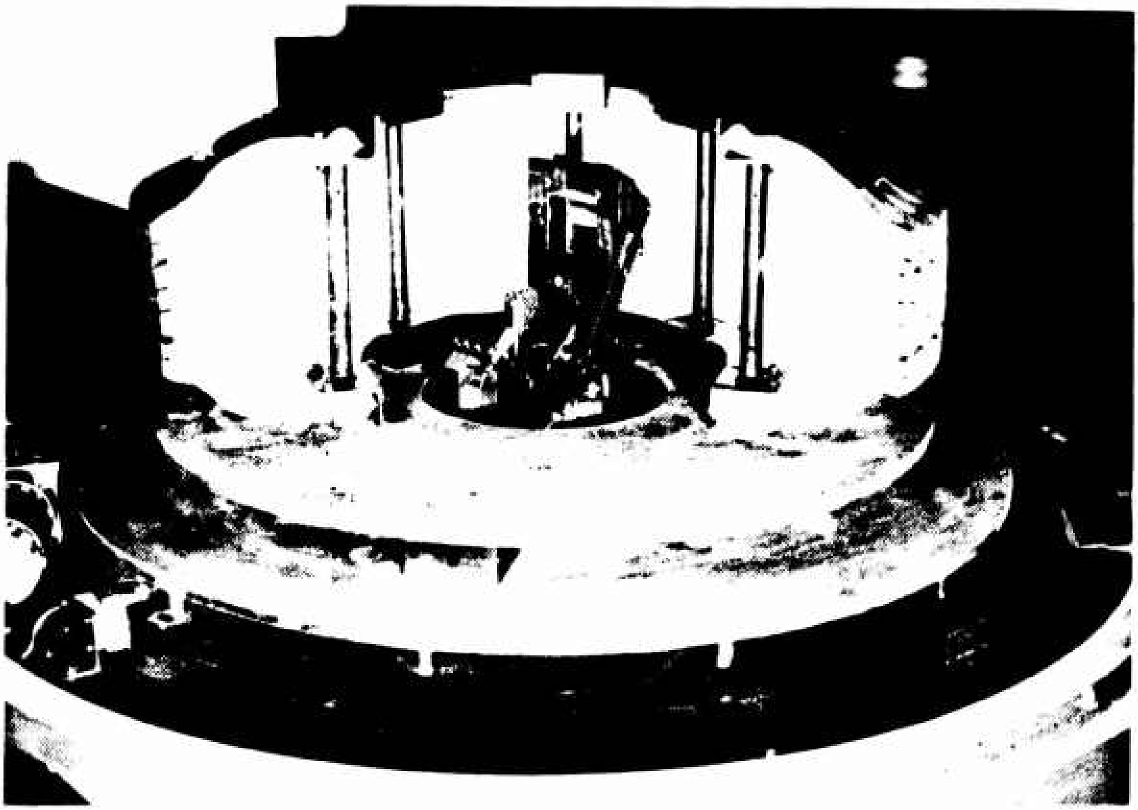


FIGURE 2
Bead Separation By Metal Spreaders

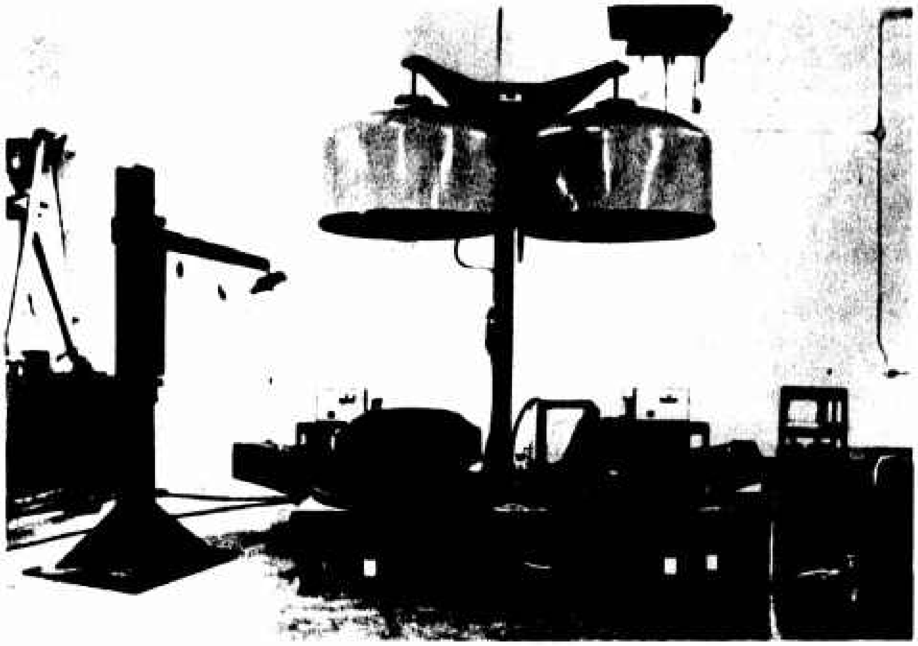


FIGURE 3.a. Typical Test Machines For Aircraft Tire Analysis

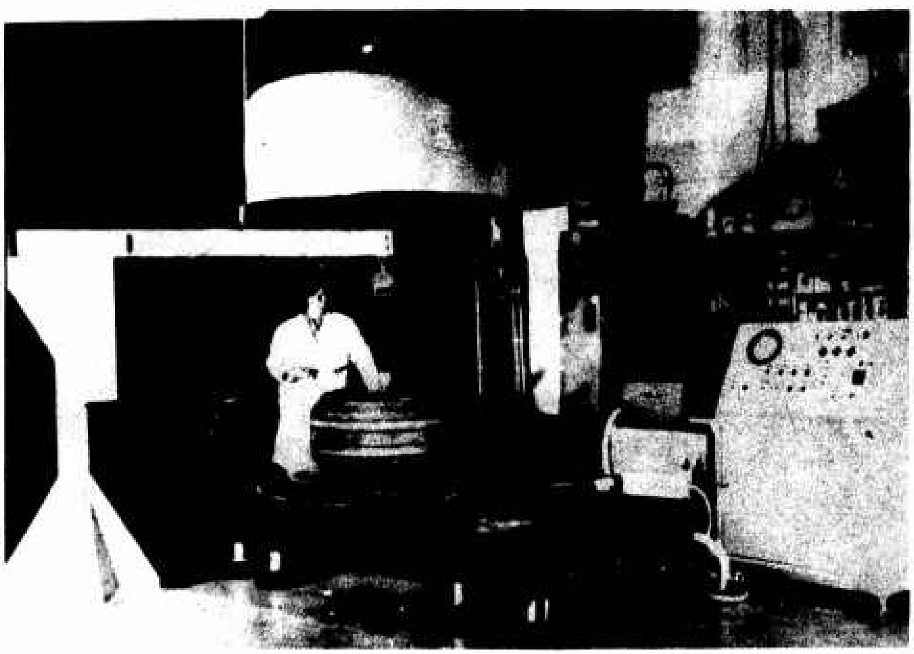


FIGURE 3.b. Typical Test Machines For Aircraft Tire Analysis

FIGURE 3.c. Typical Test Machines For Aircraft Tire Analysis

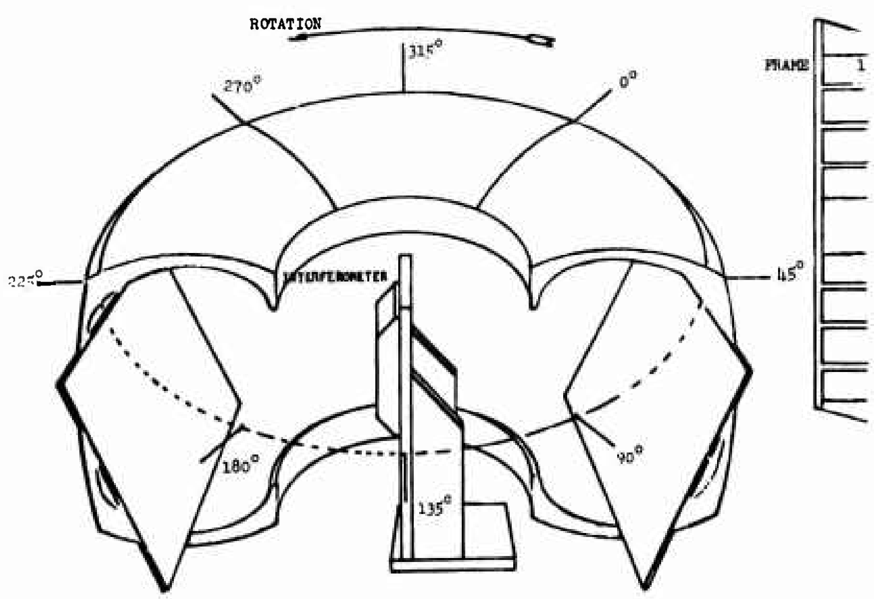


FIGURE 4.a. Bead View Holography – Mirror Placement

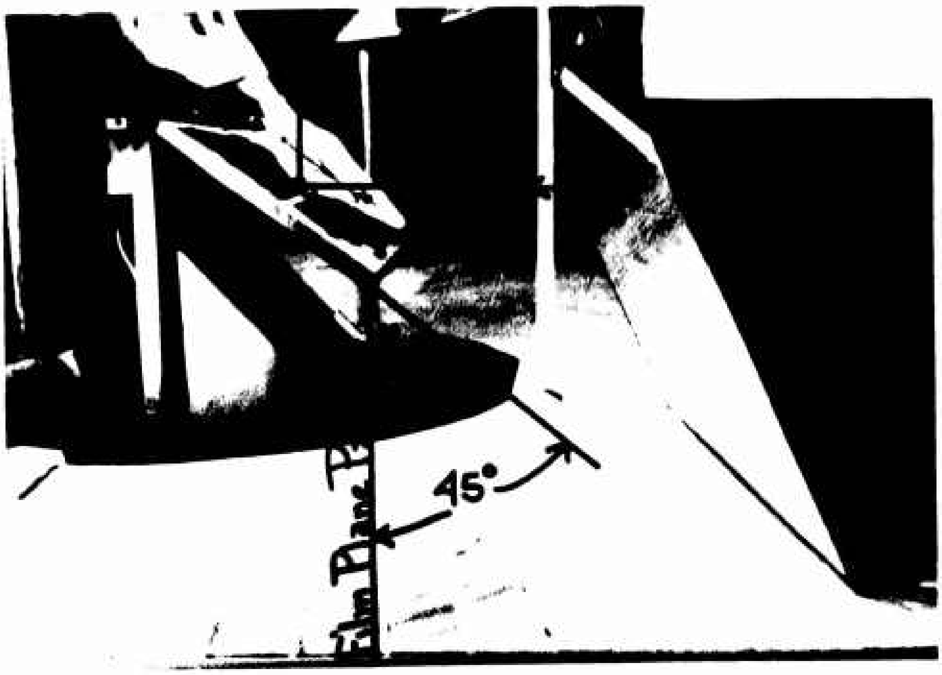


FIGURE 4.b. Bead View Holography – Mirror Placement

FIGURE 4.c. Bead View Holography – Mirror Placement

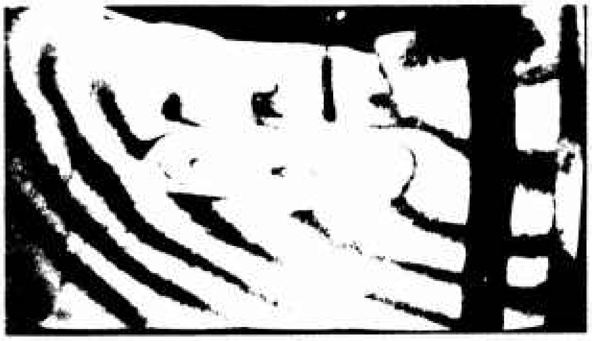
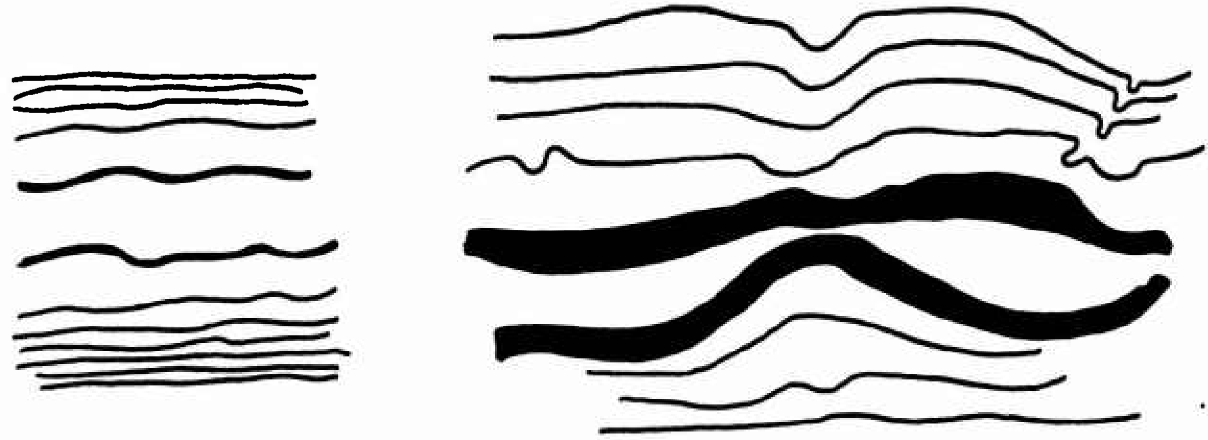


FIGURE 4.d. Bead View Holography — Mirror Placement

In a situation where there is an interply separation inside the structure, not only do we get this displacement as a result of having put a negative pressure on the surface, hence lifting the entire surface; but there is also an added displacement as a result of the air expansion inside the void or interply separation. Whenever we observe the concentric ring pattern of a separation, it has a background fringe structure surrounding the separation which tells us the relative strength of that region, in addition to the fundamental pattern which reveals the void or separation itself. So, in summary, we observe a background displacement pattern as well as the typical bull's eye pattern. This pattern reveals the displacement which is associated with any separation, or lack of structural integrity as you will note in Figure 5.

Next let us explore this background pattern which reveals the general strength of the tire. For example, if we look momentarily at the turn-up region or the flipper edge of the tire and rotate the tire circumferentially (reference your observation point as being the center of the inside of the tire) and assume that the tire's internal construction geometry remains the same within very close tolerances, as does the relative strength in that region; we will then note in the hologram that the fringe lines are always uniform and very beautifully behaved as depicted in Figure 6-A. If the geometrical components inside the tire are straight and geometrically symmetric, the fringe lines or contour lines will be geometrically symmetric. The tire has stretched uniformly due to the geometrically symmetric construction detail. In other words, the fringe lines merely correspond to the stretch nature of the tire. Had there been an interply separation in the tire it would have exhibited itself with its own characteristic pattern which is a direct measure of its given size. If the separation is deep or farther away from the observer (near the tread), there will be fewer circular fringes or concentric circles. Consequently, we can resolve the general position of the separation in the structure as well as determine its relative depth in the tire. As you look from left to right, parallel to the bead, you will notice that the fringes are extremely linear and horizontal. If you take a tire in your hands and

FIGURE 5 Background — Structural Uniformity as Opposed to Structural Integrity or Separation



6.a. Excellent

6.b. Poor

FIGURE 6 – Structural Uniformity

rotate it around your head circumferentially (with your head at the center of the tire), wherever you look circumferentially (assuming you have X-ray vision), it should be the same geometrically. On the other hand, if you observe the tire in the radial direction, there are different cross-sectional thicknesses, different strengths, and therefore the fringe spacing is different. Hence from the above comments, all holographic fringes (aside from the pattern caused from changes due to variations in the index of refraction during the measurement which enhances the read-out) run horizontially from left to right and have different spacing up and down. Now what would happen if we had a tire where there were variations in the height, say at the turn-up? This variation could lead to a variation in the strength. Then instead of the classic very uniform linear horizontal fringes, we would see fringes which wander up and down as we move circumferentially around the tire. This would mean that we are getting a different magnitude of stretch as we move circumferentially around the tire as depicted in Figure 6-B.

When a tire is constructed with near perfect geometrical proportions and such exacting geometry is further coupled with near perfect adhesion throughout, the fringe pattern will be highly uniform. This happens because the tire carcass responds, stretches, or elongates due to the applied load or stress induced by the vacuum in a highly regular or uniform manner. In other words, if the strength of the tire is uniformly symmetric, the fringe pattern will be uniform. In a highly uniform tire, we find the separation rate propagating more slowly than in the non-uniform tires. Higher shear stresses as well as higher temperatures develop in non-uniform tires resulting in the higher propagation rates. For example, a quarter inch separation in a 40 x 14 aircraft tire will go through 200 or 300 cycles or landings before propagating significantly if it is in a very strong carcass. If, on the other hand, it is in a very weak carcass as revealed by non-uniform fringe contour lines, it may propagate to failure within 25 to 30 cycles, especially if it is in the shoulder region. If the background fringe pattern is geometrically non-uniform, cord tension will vary over a greater range and fatigue will set in much faster. Separations will evolve more readily and will propagate at a higher rate. If however, the background fringe pattern is uniform, separations will only rarely appear over the first hundred cycles; and when they do, they will propagate much more slowly. Hence in aircraft tires, it is particularly important to take this background structural uniformity into account when predicting the rate of propagation of a given separation at a given location. The performance characteristics of a given tire construction will be critically dependent upon the observed state of the tire's structural integrity.

In summary, it should be noted that a large structural uniformity data base must be established before realistic acceptance-rejection criteria can be established on a given type of tire. The existence and size of separation is not nearly as important an observation as the overall structural uniformity, unless of course the separation is well over an inch in diameter and it is in a critical geometrical position. One must always judge the criticality of the size of a given separation as a function of the observed carcass strength which is revealed by this general structural uniformity.

The type of data which we reference here, can be obtained over a period of time by routine monitoring of commercial carrier fleets. Tires which develop dangerous separation

characteristics can be run out on indoor test wheels to minimize the danger to the commercial operation.

Now there are some basic questions at this stage which we should begin to ask ourselves. What is the incidence of interply separation in a typical sample of aircraft tires? Given the fact that they exist in a given structure, what is the probability of failure during the original tread life: R-0, or R-1; the first recap level, or R-2: the second recap level, etc. In general, there are fewer separations in aircraft tires than most of us realize. It turns out however in a few isolated cases, that abnormal outcropping of separations in given tire sizes do exist as a result of construction mistakes, poor workmanship, contamination, etc. Often modest changes in tire construction can reduce separation problems.

One of the common causes of separation in new tires is due to the existence of pieces of "poly" left in the tire when these protective sheets are pulled off the original stock material during the building of the tire. An example of dealing with separation problems by changing construction details in 40 x 14's is to reduce cord diameter and increase skim coat thicknesses to provide greater insulation between plys. In one particular test carried out on 100 new 49 x 17 aircraft tires, the author found that 3% of the tires contained separations over one inch in diameter at the turn-up edge due to pieces of poly. The fact that at least one of these could have lead to a critical failure within its normal life expectancy is without a doubt.

But now let us come back to the basic point. Given the fact that separations do exist in aircraft tires, how many exist, and when they do exist in a given construction, how fast do they propagate? When and under what circumstances do they lead to failure? What is the proper time to take tires off of a given system so as to get the maximum usefulness out of a tire purchased?

To get a preliminary feeling for the answers to these questions, (a final answer is not yet possible), six descriptions follow of random samplings from a mixture of R levels taken from a few thousand aircraft tire tests. Let us choose first a random sampling (Sample #1) of 100, 20 x 4.4 tires. About 9% of this sample were separated. Based on our data to this date, we would consider about 6% of that 9% to be moderately critical, implying that there is a given probability of failure within the life span of the carcass or more specifically, that there is a high probability that the tire would not pass a qualification test. Within this 6%, about 3% of the tires contained one quarter inch or larger separations combined with poor structural uniformity such as non-uniform cord tension or fatigue. On the other hand as a comparison to this sample, the author has observed a group of 300, 20 x 4.4's (Sample #2) in which not one single separation was found. Within this group, probably not more than one to three would fail the basic qualification test for the 20 x 4.4. However, we realize that the indoor qualification wheel test is undoubtedly more severe than the real world situation. In actual usage, all 300 of these tires would probably have lived out their full carcass lives over two or three R levels without mishap.

A more typical case for 20 x 4.4's would be to find three to five seriously defective tires among a sample of 500, or about 1%. The percentage of critically defective tires in a given sample lot will vary significantly when testing tires manufactured by different companies. In other words, a much more significant variation in data appears when comparing different retreaders. The quality of tires also vary as a function of the date of manufacture.

Next not a more typical random sample (Sample #3) in 30 x 8.8 tires. In this sample, of the 100 tires chosen, only two were separated. And of those two tires, only one had a very high probability of premature failure since critical non-uniformity surrounded the separation.

Our next sample (Sample #4) is of 100 tires, size 40 x 14 – Manufacturer A. In this case, 41% of the tires were seriously defective and rejected, based on a rejection criteria for separations of ½±¼" or larger where the variation, ¼", is a function of the overall strength of the carcass or structural uniformity. Most of the separations in the 41% were serious shoulder and/or splice separations. Less concern was given to the separations existing in the center or crown region. The ±¼" variation was used to single out strong and weak tire carcasses. In other words, a separation as large as three quarters of an inch would be allowed in a tire with a strong carcass, whereas a separation only as large as one quarter of an inch would be allowed in a carcass which was weak and fatigued. We should also note that a few tires in the 41% rejection criteria were rejected solely on the basis of extremely weak and loose carcasses; that is, carcasses containing no separations. We tested a number of these rejects (from the moderately-high-probability-of-failure types to the very-high-probability-of-failure types) on the indoor test wheel and they all, without exception, failed prematurely.

The question: "What do you mean by critical separation?", or "How does one establish an acceptance-rejection criteria?" need to be answered. Acceptance-rejection criteria must be established on a very substantial data base; 100 tires is not substantial enough. After testing over 1000, 40 x 14's, we began to establish a good degree of confidence in terms of an acceptance-rejection criteria, which is ½±¼" where the variation of ±¼" as mentioned above is a function of the carcass strength. Now let us look at a sample of 100, 49 x 17's, which is Sample #5. Here, 11 tires were rejected. Although in this case we have not looked at enough tires to clearly establish an acceptance-rejection criteria, our general feeling is that separations up to one inch in diameter in the crown area are acceptable for an additional R level as long as the carcass is strong. However, only separations smaller than one quarter inch would be tolerated in the turn-up area or shoulder areas.

Now let us digress momentarily to point out that the seriousness of a separation is established while observing, as a result of repeated tests through many R levels, the propagation rate of the separation as a function of the number of landings. In addition, the propagation of separation as a function of the number of taxi-take off cycles has been studied (the author has studied repeated tests on approximately 27 tires) on indoor test wheels. There is a desperate need for more indoor test data, since we have only scratched the surface of this immensely fruitful area of research. Furthermore, one establishes a very good feeling for how fast a separation propagates by observing from R level to R level how fast the tire is deteriorating both from the point of view of the structural uniformity and the structural integrity (the size of the separation as a function of the number of landings). By observing the increase in size of very small separations from R level to R level, one obtains a feeling or judgment as to how many landings a tire will go through before the separation reaches a size where the tire will fail. We have observed both real world failures (failures on actual aircraft) in addition to failure cases which were simulated on indoor test wheels.

Next let us look at a larger sample (Sample #6) of 40 x 14's – Manufacturer B. In this distribution of 1000 tires, there is a total mixture between R-0's, R-1's, R-2's, henceforth, on up through the R-5 level. The distribution contained more R-2 levels than any other specific level. The rejection over the first 1000 tires based on our data base was 21.5%; however, these rejections were based on both separations and loose splice detail combined with overall cord looseness and tire fatigue. In other words, about 15% ±3% of the total would be considered to be critical. And, in this case, we would define critical as meaning those tires which would have an above average probability of failing had the tire not been rejected prior to the next R level. A special note should be made that many of the tires we observed which contained critical separations were removed from service prior to failure due to cuts, skid burns, etc. Had the tire in the sample been more resistant to cuts, for example, the airline would have experienced even more than the typical one failure per month which was their situation. A brief note should be made that many of the serious shoulder separations which were in structural weak areas were not revealed by air needle injection.

A few additional comments might be in order with regard to the distribution of 100 new 49 x 17 tires. One percent, or one tire, contained a very critical shoulder separation which could have led to a serious problem. Three percent, or three of the tires, contained crown separations with an average size of two inches in diameter. Separations of this size could lead to a problem previous to the next R levels. Five percent, or five tires, contained separations at the turn-up, flipper strip edge, and in the apex strip region above the beads. Another one percent, or one tire, exhibited very poor cord adhesion characteristics. Upon examining the eleven tires of special concern, we might note that tire #1 contained a crown separation over ½". Tire #2 contained a 1" crown separation. Tire #3 contained a separation in excess of 1" at the turn-up. Tire #4 contained a separation in excess of 1" at the turn-up. Tire #5 exhibited cord socketing to an extent which could lead to a serious problem. Tire #7 contained a 2" separation at the bead apex. Tire #8 contained a 1" separation at the bead apex. Tire #9 contained a separation in excess of 3" in the shoulder. This tire obviously had a high probability of premature failure – and soon. Tire #10 contained a 3" separation at the turn-up. Tire #11 had weak tread adhesion in general. The remaining 89 tires had a very low probability of failure and were excellent candidates for further retreading. It is important to note that all of these 100, 49 x 17's were new R-0's. Throughout the R-0 level, we would consider only one of these above eleven to have a very high probability of failure prior to the next R level; this tire being tire #9, – the one with the 3" separation in the shoulder. Had any of the above eleven tires been overloaded and underinflated at the same time, at least five of the eleven would have had a high probability of premature failure.

Considering R levels beyond R-1, there now is a probability of failure which begins to become noteworthy even under normal loading conditions in tires #10, 3, 7; the tire containing the 3" separation at the turn-up, the tire containing the 1" separation at the turn-up, and the tire containing the 2" separation at the apex.

We should again ask ourselves the question, "What constitutes a critical defect?", that is, a defect which has a very high probability of failure prior to the next R level. And, how does one go about getting data which relates to defect criticality?

Allow me to digress momentarily to say that the beauty of truck tire testing lies in the fact that the data is so much easier to obtain. One simply sorts out defective truck tires from good truck tires, selects several hundred, and then mounts them on trucks in fleets with defective tires running alongside good strong tires to minimize any possible danger of a serious situation occurring. Over ensuing months, and observations of many tire failures, it is easy to establish a clear cut criticality, or acceptance-rejection criteria. Such data can certainly be obtained in a one to two year period in the field, or over a few weeks employing indoor test wheel data.

But, what can one do to establish criticality in the case of aircraft tires? First, one tests a very large number of tires and separates out those which have a lack of structural integrity (separations) and/or lack of structural uniformity (poor construction geometry, loose cord tension, fatigue, low adhesion, etc.). With aircraft tires, we cannot submit them to actual field test runs as in the case of truck tires.

Instead, we must sort out those tires on an indoor test wheel to run them out to failure. After having done so, we must establish the basic rate of propagation as a function of the number of cycles or landings. The obvious problem lies in the fact that real world failure data is nearly impossible to obtain and the gathering of data on an indoor wheel is slow and expensive. One researcher can direct a study on a thousand truck tires in the same period of time it takes to carry out failure analysis on 50 aircraft tires. Further work in this area is critically needed. The best acquisition of data comes through monitoring tires in a typical carrier's fleet. As an example of the monitoring of a given fleet, note tire sample #7 in which 2.6% of a distribution of 2200 tires, size: 46 x 16 were rejected. Here, there existed a clearly defined probability of failure in service had these tires been allowed to remain in service. Note Figure 7 which summarizes the various samples presented thus far.

Before proceeding to a discussion of results on indoor test wheels to establish defect size criticality, it might be interesting to point out that in the case of a 40 x 14 tire, we made a mistake in the early stages of our testing and allowed a tire which contained a 2" separation to get placed into the "tires accepted" category as opposed to the "tires rejected" category. At that time, we were using an acceptance-rejection criteria of ½". That tire, containing a 2" separation, was accidentally mounted on an aircraft *and it failed on the fifth taxi-take off.* We were fortunate in that the failure did not lead to as serious a situation as it could have. As a result of this experience, we believe that a 2" separation would obviously go to failure very quickly.

But what about the case of the ¼", or ½", or ¾" separations? How soon would they fail? Our next step was to take these types of separations to the indoor test wheel and to observe their propagation as a function of the number of cycles. As our first example of the indoor test wheel, we will look at a 40 x 14 - 21 tire and observe the increase in the separation diameter propagation as a function of the number of taxi-take off cycles. In this first case (note

Sample	Size	Quantity Tested	% Rejection	High Prob. of Failure	Lower Prob. of Failure
1	46 x 16	2200	2.6%	1.7%	0.9%
2	20 x 4.4	100	9.0	6.0	3.0
3	20 x 4.4	300	0	0	0
4	30 x 8.8	100	2.0	1.0	1.0
5	40 x 14-A	100	41.0	22 - 25	16 - 19
6	40 x 14-B	1000	21.5	12 - 18	3.5 - 9.5
7	49 x 17*	100	11.0	1.0	10.0

FIGURE 7 – Summary of Rejection Rates for Various Sample Tests

*New R-0. All others: R-1 through R-7 with most at or near R-2.

Figure 8), we observed in the original carcass a 7/8" diameter separation. The tire was then mounted on the indoor wheel and after a brief warm-up period, the tire was cycled through five taxi-take off cycles. The tire was then taken off the test wheel, dismounted, and then reholographed. At this time, we observed that the 7/8" diameter separation had grown to 1½" in diameter. The process was repeated for another five taxi-take off cycles and the 1½" diameter separation had now grown up to 6" in diameter. Other separations had grown in diameter which were close to the original 7/8" diameter separation. These separations, as they had grown, had also joined up into the above mentioned 6" diameter separation. Again, a 1/8" diameter separation in this same carcass, which was originally close to the previously mentioned 7/8" diameter separation, grew after five cycles to a 3/4" separation in an additional five taxi-take off cycles up into the 6" separation mentioned earlier. At the same time, an original ½" diameter separation, which was at a further distance from the original two separations mentioned, after five taxi-take off cycles had grown to 1¼". Then after another five taxi-take off cycles had reached out and joined into the above mentioned 6" separation. In other words, the original 7/8" diameter, 1/8" diameter, and ½" diameter separation all grew significantly and finally ended up after ten taxi-take off cycles in a single 6" diameter separation which then, in turn, went to failure after six additional cycles.

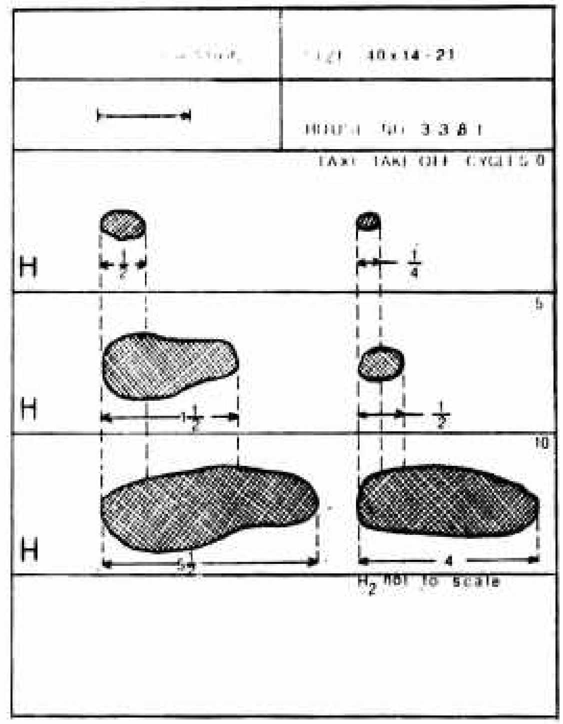


FIGURE 9
U.S. Navy Tire No. 2 – Indoor Test Wheel
40 x 14 - 21

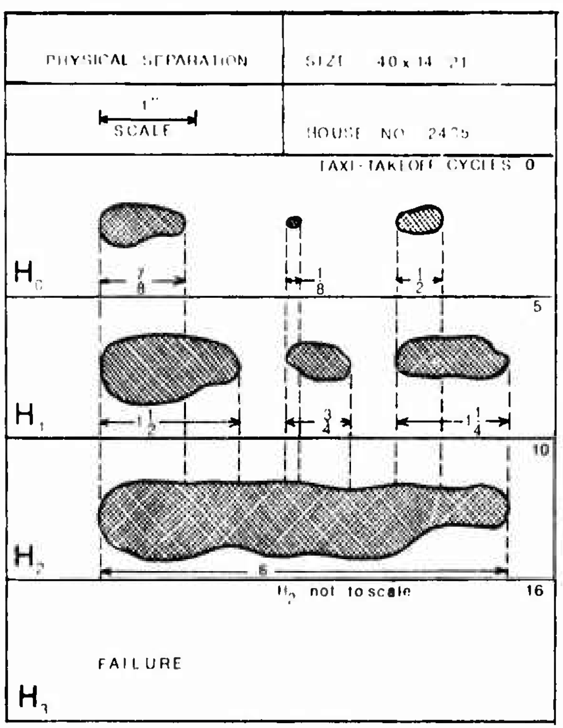


FIGURE 8
U.S. Navy Tire No. 1 – Indoor Test Wheel
40 x 14 - 21
Physical Separation versus Taxi-Takeoff Cycles

Let us give an additional example in a 40 x 40 - 21 (Figure 9) aircraft tire. In this tire once again, there was a considerable lack of structural uniformity throughout. In this case, a ½" diameter separation in the original measurement propagated to a 1½" diameter separation after five cycles, which in turn, propagated to a 5½" diameter separation after yet another five cycles. Another original ¼" separation propagated to ½" in diameter after five cycles, which, in turn, propagated to 4" after five more cycles. So, therefore, we note that separations in the ¼" to ½" category propagate quite quickly, particularly when they are in a tire which is structurally weak and/or the separation is in a shoulder region as the above cases were.

Figure 10 is an example of an extreme case of separation which existed in a tire removed from an aircraft. The tire

FAILED - 1 cycle

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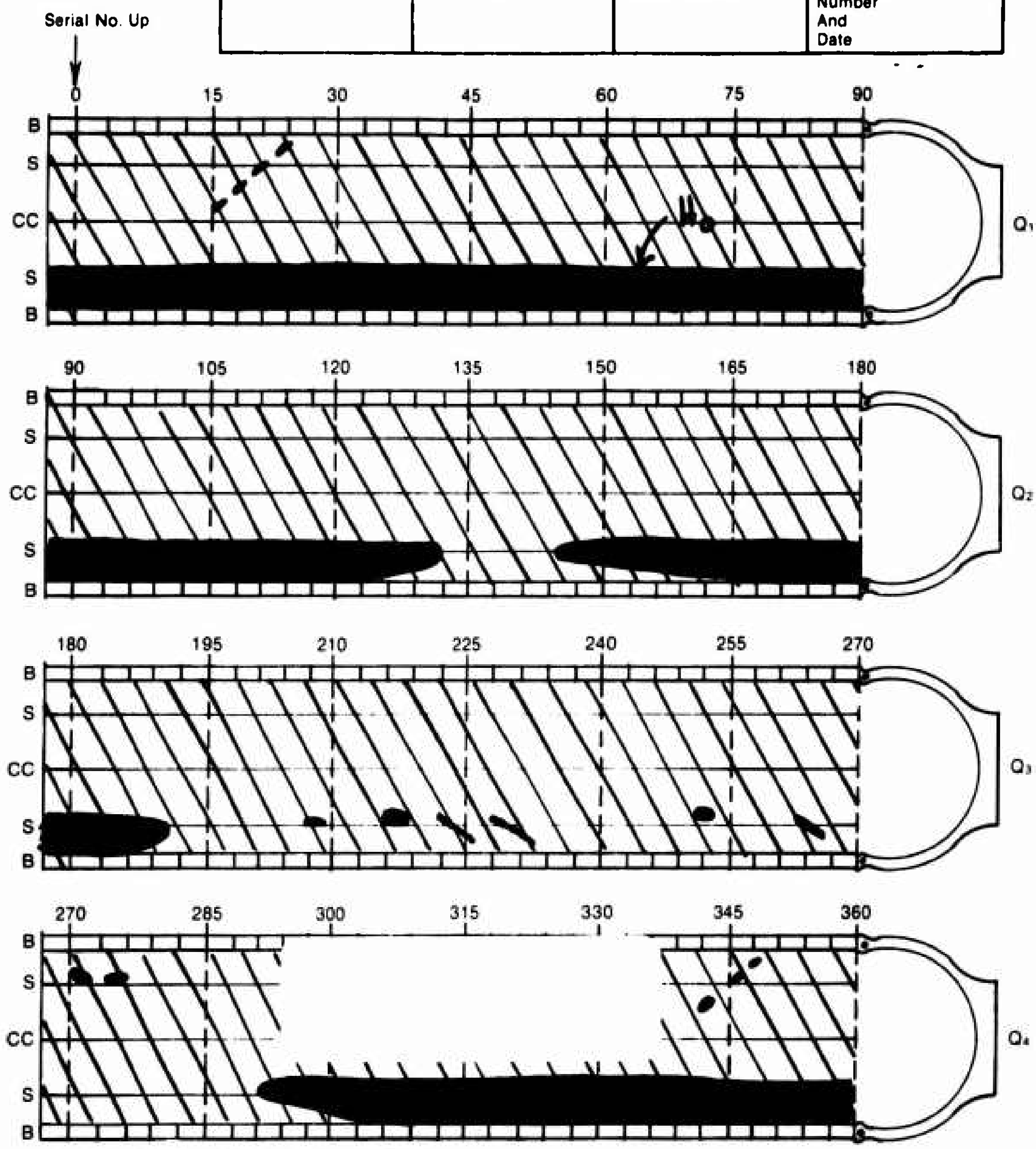
Customer NAVY	Tire O K Special Study ✓ Reject	Size 40x14/21	House Number H59-Nav.
Mileage 5	Retread Number R1+?	Carrier In Out	Serial Number 107X7298
Date Received	Date Shipped	Shipper Number	Holograph Number And Date



B = bead S = shoulder CC = crown center

FIGURE 10
Indoor Test Wheel Data Extreme Case 40 x 14 - 21

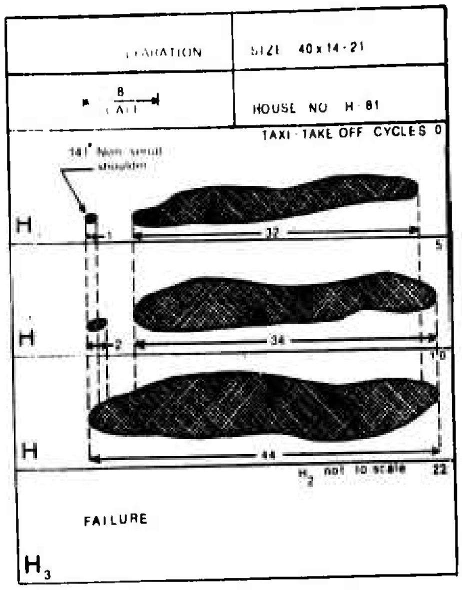


FIGURE 11
U.S. Navy Tire No. 3 – Indoor Test Wheel
40 x 14 - 21

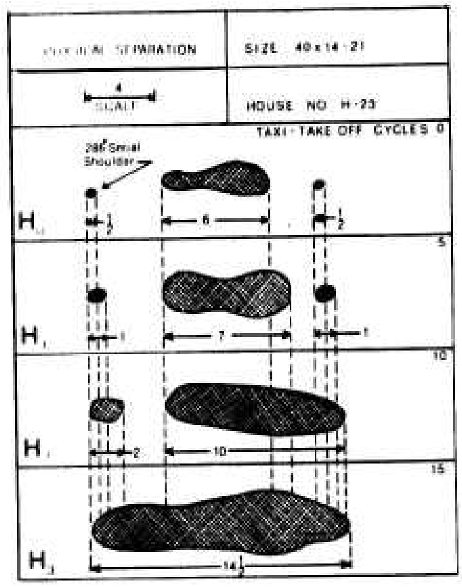


FIGURE 12
U.S. Navy Tire No. 4 – Indoor Test Wheel
40 x 14 - 21

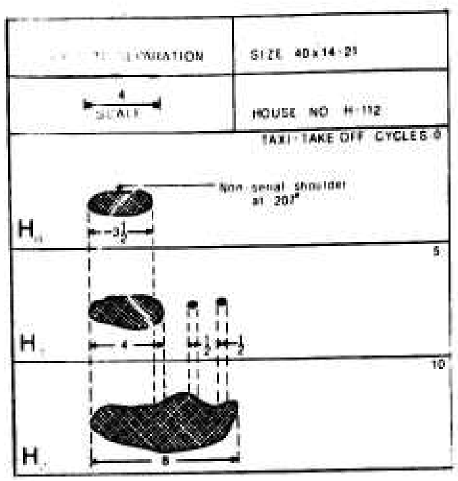


FIGURE 13
U.S. Navy Tire No. 5 – Indoor Test Wheel
40 x 14 - 21

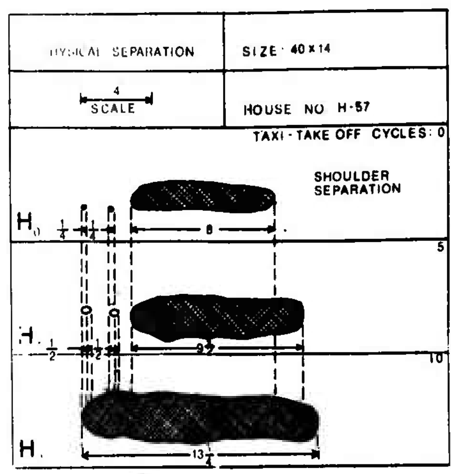


FIGURE 14
U.S. Navy Tire No. 6 – Indoor Test Wheel
40 x 14 - 21

showed no visible evidence of separation, however its chart in Figure 10 reveals the extent of physical separation on the non-serial side shoulder at the time the tire was first holographed. This tire threw its tread on the indoor test wheel at the start of the second taxi-take off cycles.

Next, note four more realistic examples of propagation in Figures 11 through 14. Figure 11 depicts the propagation of a 1" separation (at 141° from the serial number in the non-serial shoulder) and an adjoining 32" separation in the shoulder of an R-4 tire which went to failure in 22 cycles.

Figure 12 depicts the propagation of two small ½" separations and one larger 6" separation which failed after 15, or on the 16th cycle. Figure 13 reveals the amount of propagation which occurred after 10 cycles. The separation originally was a 3½" shoulder separation at 207° from the zero degree serial number position. Figure 14 depicts similar propagation after 10 cycles.

Next, allow me to give a dozen examples of propagation of separation in aircraft tires – size 26 x 6.6. Note Figure 15 which is a summary of these examples. In the first 26 x 6.6

TIRE #	NAVY SERIAL NUMBER	SEPARATIONS	CYCLES TO FAILURE
1	4385	2-1/4", 1-3/4"	19
2	000584	2-1"	11
3	1036	1-3/8"	11
4	40170125	weaknesses at 175°, 70°	15
5	9-66-87671	1-3", 1-2", 1-3/4", 1-1/8"	1
6	7-67-03703C30C	1-3/4", 1-1/8"	28
7	1280AK0873	1-3", 14-1/2", 6-1/8", 1-3/4", 11-1", 2- 1-1/2"	10
8	1271AK0680	weakness at 150°	26
9	1031	1-1"	16
10	2115AK0281	7-1/4", 2-1/8", 1-1/2" 1-1", weakness at 22°	10
11	1-66-38474	3-1", 2- 1-1/2"	7
12	02278428	Control Tire - Uniform no separations - Excellent Quality	Did Not Fail

FIGURE 15
U.S. Navy Indoor Test Wheel Data for Twelve 26 x 6.6 – 16 Ply Tires

tire, a ¼" separation at 127^{0} in the crown area of the tire propagated to a ½" separation after five cycles, which in turn propagated to 5/8" after five more cycles, which in turn propagated into a 5" separation after yet another five cycles. An original ¼" separation at 143^{0} propagated to ½" after five cycles, and then propagated to 3/4" after yet five more cycles, and finally propagated into the 5" separation mentioned above after five more cycles. A third separation at 153^{0} in the crown which was ¾" in diameter propagated to 7/8" in five cycles, which in turn propagated to 1" in five additional cycles, which in turn joined into the above mentioned 5" separation. The 5" separation then, in turn, failed after four more cycles. From the above, we note that separations ranging from ¼" to ¾" propagate quite rapidly as a function of the number of cycles. Moreover, these individual separations have propagated this quickly as a result of the fact that they were clustered quite close together. Had these separations been further apart, or had they existed singularly, they would not have propagated as fast. This example provides us with direct information on our ½" separation criteria used by the U.S. Navy. (Present rejection criteria is ½").

Next let us look at an example of a 1" separation in a 26 x 6.6 tire (note Figures 17-A and 17-B). This separation propagated after five cycles into a 2" separation, which, in turn, after five more cycles propagated into a 4" separation which, in turn, propagated to failure at the beginning of the eleventh cycle.

Another description (note Figure 18) is of a 26 x 6.6 tire (#3) which had a very weak carcass, namely, poor structural uniformity. This tire originally had a separation, 3/8" in diameter, which propagated to a 3" separation in five cycles, which in turn, propagated into a 12" separation in five additional cycles, which, in turn, failed before the next cycle was completed. Note that poor structural uniformity has a strong influence on the propagation rate.

Next allow me to provide a brief example of a tire (#4) which showed extreme non-uniformity in weakness throughout the carcass, but contained no separation initially (note Figures 19-A & 19-B). It exhibited the fact that a tire, in this case a new R-0, which had extreme amounts of structural non-uniformity would develop separations very quickly. In this case, after five cycles a ¼" separation

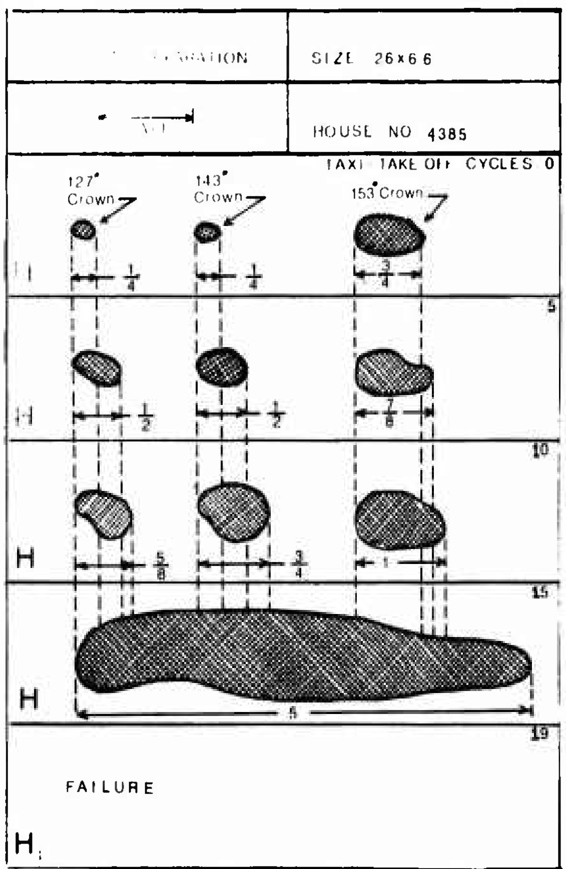


FIGURE 16
U.S. Navy Tire No. 1 – Indoor Test Wheel

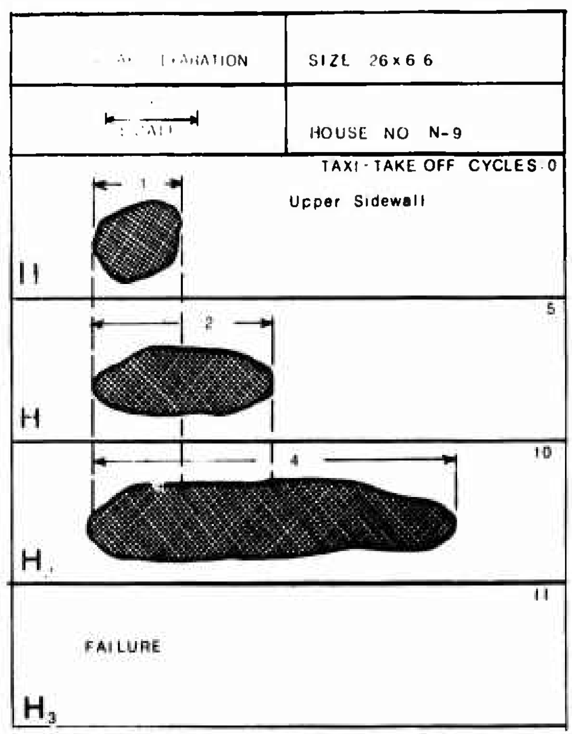


FIGURE 17.a.
U.S. Navy Tire No. 2 – Indoor Test Wheel
Propagation Pattern

Σ10

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Customer	Tire O.K / Special Study / Reject	Size	House Number
NAVY	Special Study ✓	26x6.6	N9
Mileage	Retread Number	Carrier	Serial Number
0-5-10 T.T.	R1	In / Out	000584
Date Received	Date Shipped	Shipper Number	Holograph Number And Date
			H0 - 11/25/74 H1 - 3/1/75 H2 - 5/15/75

Serial No. Up

* Spec. Note - ~~Gripped~~ Won. Serial Side Up - Tested

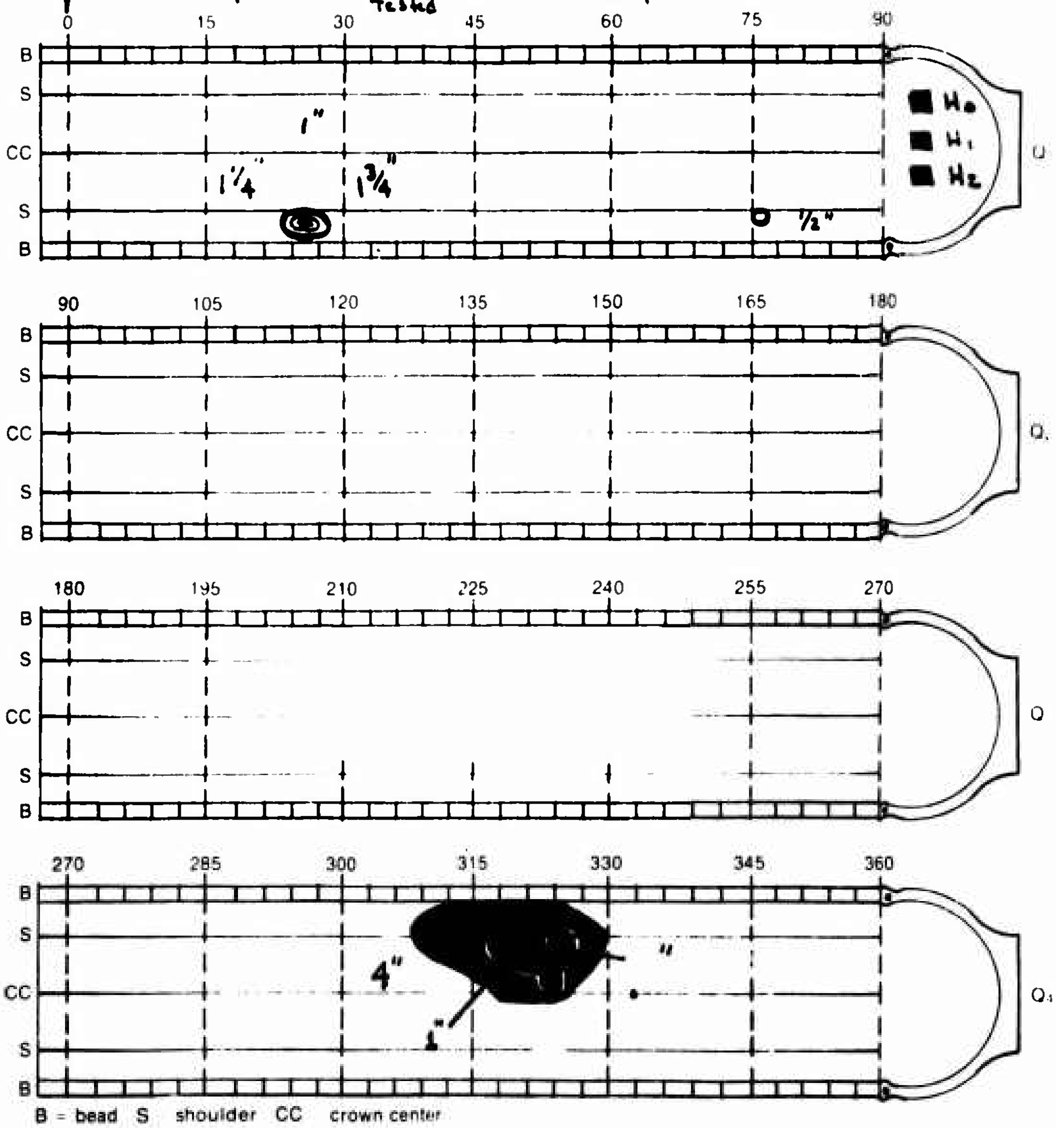

FIGURE 17.b.
U.S. Navy Tire No. 2 – Separation Location & Propagation Chart

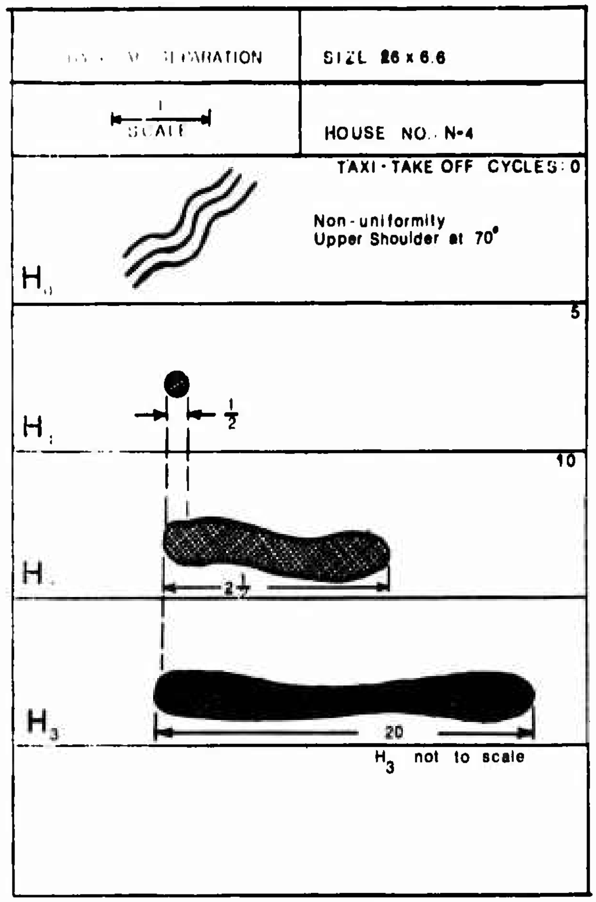

FIGURE 19.a.
U.S. Navy Tire No. 4 – Indoor Test Wheel
Propagation Pattern

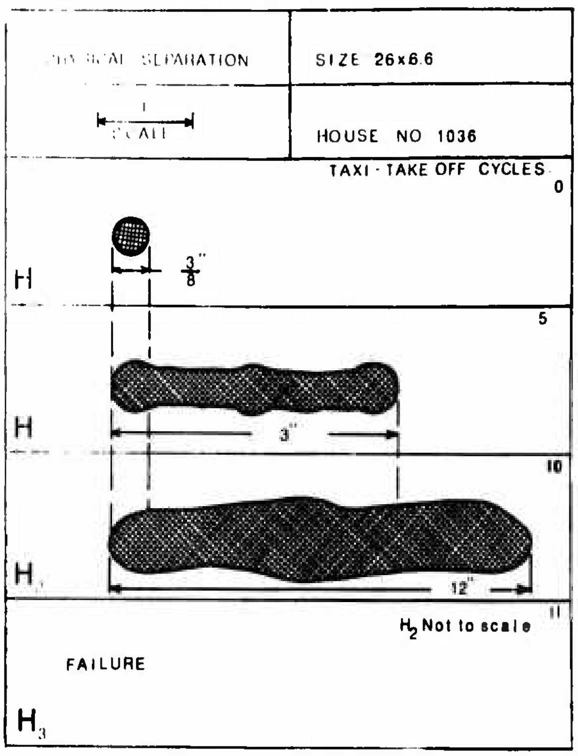

FIGURE 18
U.S. Navy Tire No. 3 – Propagation Pattern

Σ_0 Σ_5 Σ_{10}

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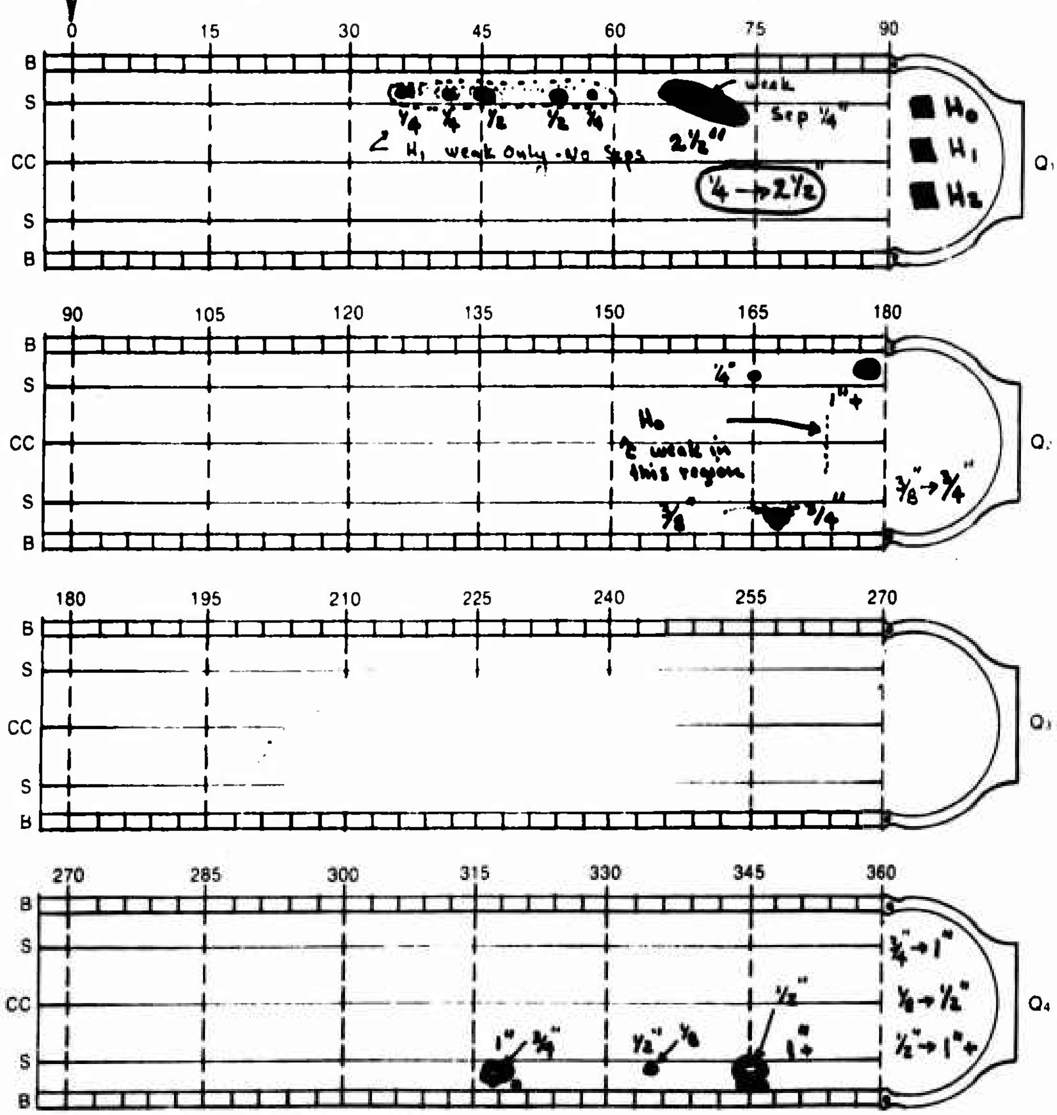
LABORATORY REPORT

Customer	Tire O K / Special Study / Reject	Size	House Number
NAVY	Special Study ✓	26x6.6	N4
Mileage	**Retread Number**	**Carrier**	**Serial Number**
5 Taxi Takeoffs each $H_0 \to H_1 \to H_2$	R_0	In / Out	40170125
Date Received	**Date Shipped**	**Shipper Number**	**Holograph Number And Date**

Serial No Up



B = bead S = shoulder CC = crown center

FIGURE 19.b.*
U.S. Navy Tire No. 4 – Separation Location & Propagation Chart

*See page 110 for the reverse side of Figure 19.b.

Notice the separation at 70°, it went from ¼" → 2½" in 5 T.T.'s - unlike truck - very fast - jump transition propagation. Proof that a tire must be tested at each R_n level where n=0, 1, 2, ... n.

Significant propagation, at what size separation will tire fail; propagation is taking place very fast.

Reverse Side of FIGURE 19.b.

evolved at the specific point of non-uniformity. This ¼" separation in turn propagated to a 2½" separation within five additional taxi-take off cycles, which, in turn, propagated to a 20" separation after five additional taxi-take offs.

Figure 20 is another example of structural non-uniformity which progressed to 20" separation within 15 cycles.

Figure 21 is a photograph of the test chart which displays early failure in an R-1 tire (#5). The cross-hatched lines represent a thrown tread which occurred after only one cycle due to the cluster of four separations between 225° and 252° in the center crown region.

Tire #6 is an example of two small separations leading to failure in, as you might expect, a larger number of cycles, namely, 28 (note Figure 15).

Another example of clustering separation can be noted (Tire #7) in Figure 22. Here, you will note that the tread had been thrown, as indicated by the parallel lines across the chart, on the 10th taxi-take off cycle.

Tire #8) (Figure 23), in this sequence, is another example of clustering as related to the geometrical position of the tire's structural integrity.

Tire #9 (note Figure 24) is a straight forward geometrically progressive propagation in a reasonably strong tire.

Figures 25-A and 25-B depict an R-1 tire (#10) with more than the normal amount of separations; however, note how the individual small separations come together to form the 5½" separation at 10 cycles.

Our last propagation example, Tire #11, is again very typical for a reasonably strong 26 x 6.6 carcass, as shown in Figure 26.

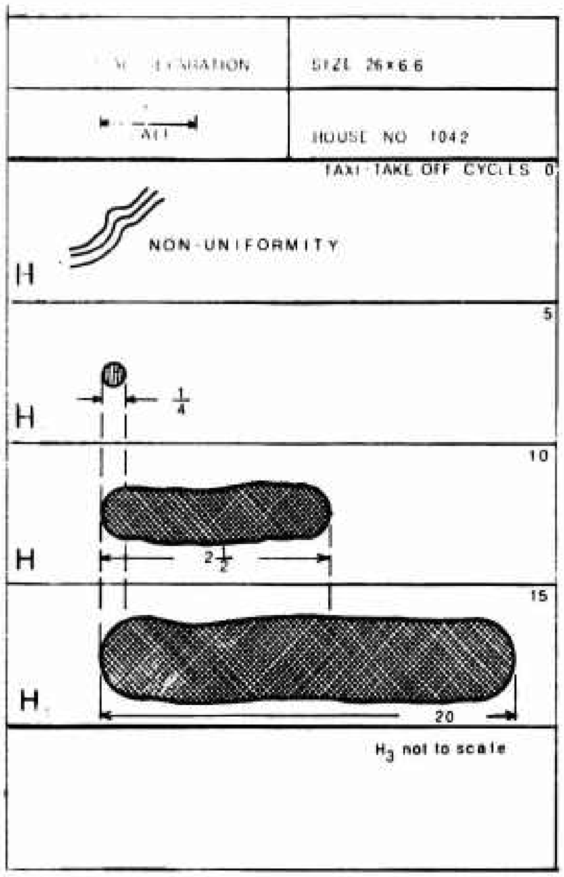


FIGURE 20
U.S. Navy Tire No. 1042 – Indoor Test Wheel Propagation Pattern

1 cycle – FAILED $\Sigma_0 - \Sigma_s$

IHI LABORATORY REPORT

Customer: NAVY	Tire O K / Special Study ✓ / Reject	Size: 26 × 6.6	House Number: N5
Mileage: $H_0 \rightarrow$ S.T.T. $\rightarrow H_1$	Retread Number: R_1	Carrier In / Out	Serial Number: 9-66-87671
Date Received	Date Shipped	Shipper Number	Holograph Number And Date

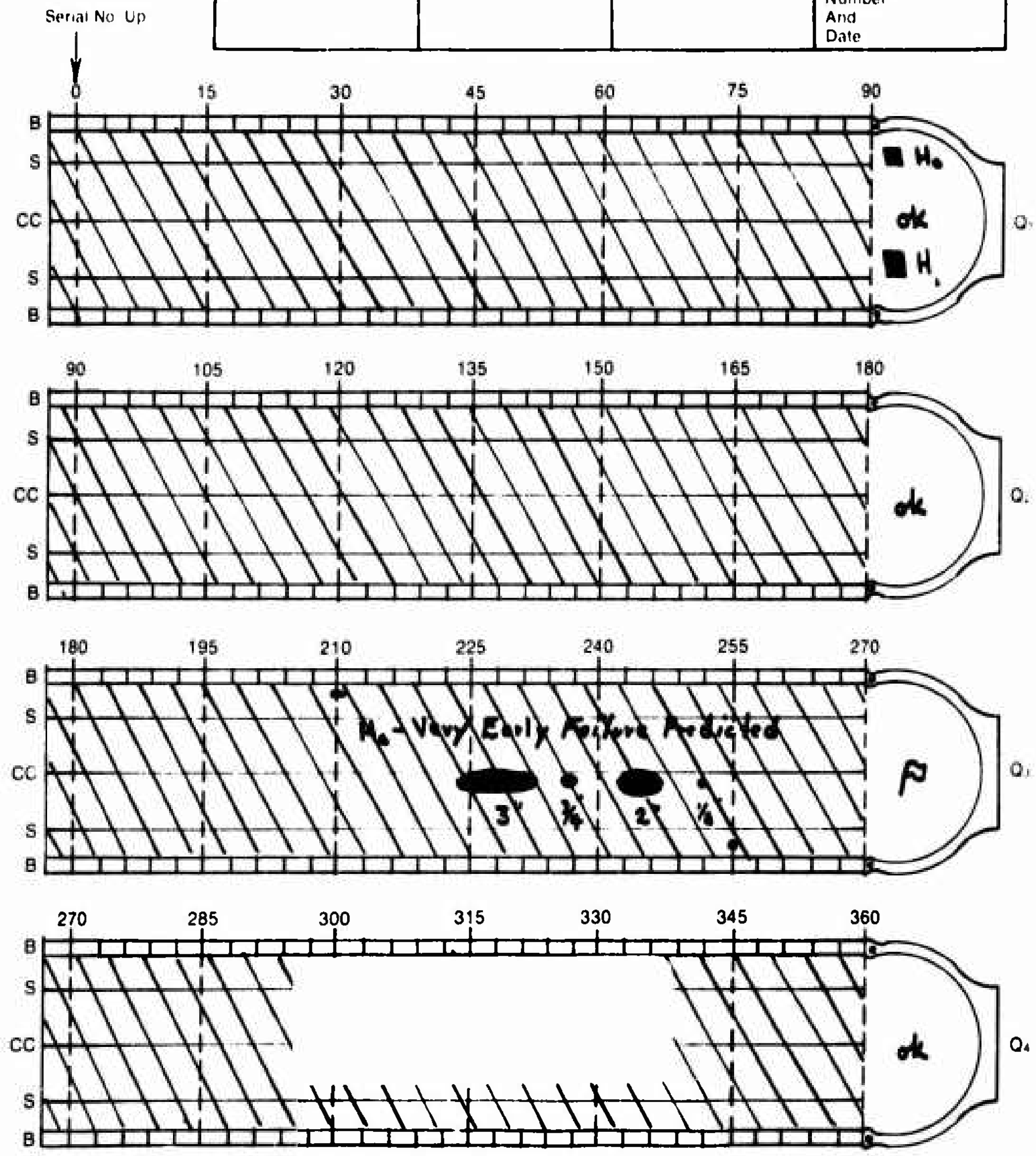


FIGURE 21
U.S. Navy Tire No. 5 – Early Failure

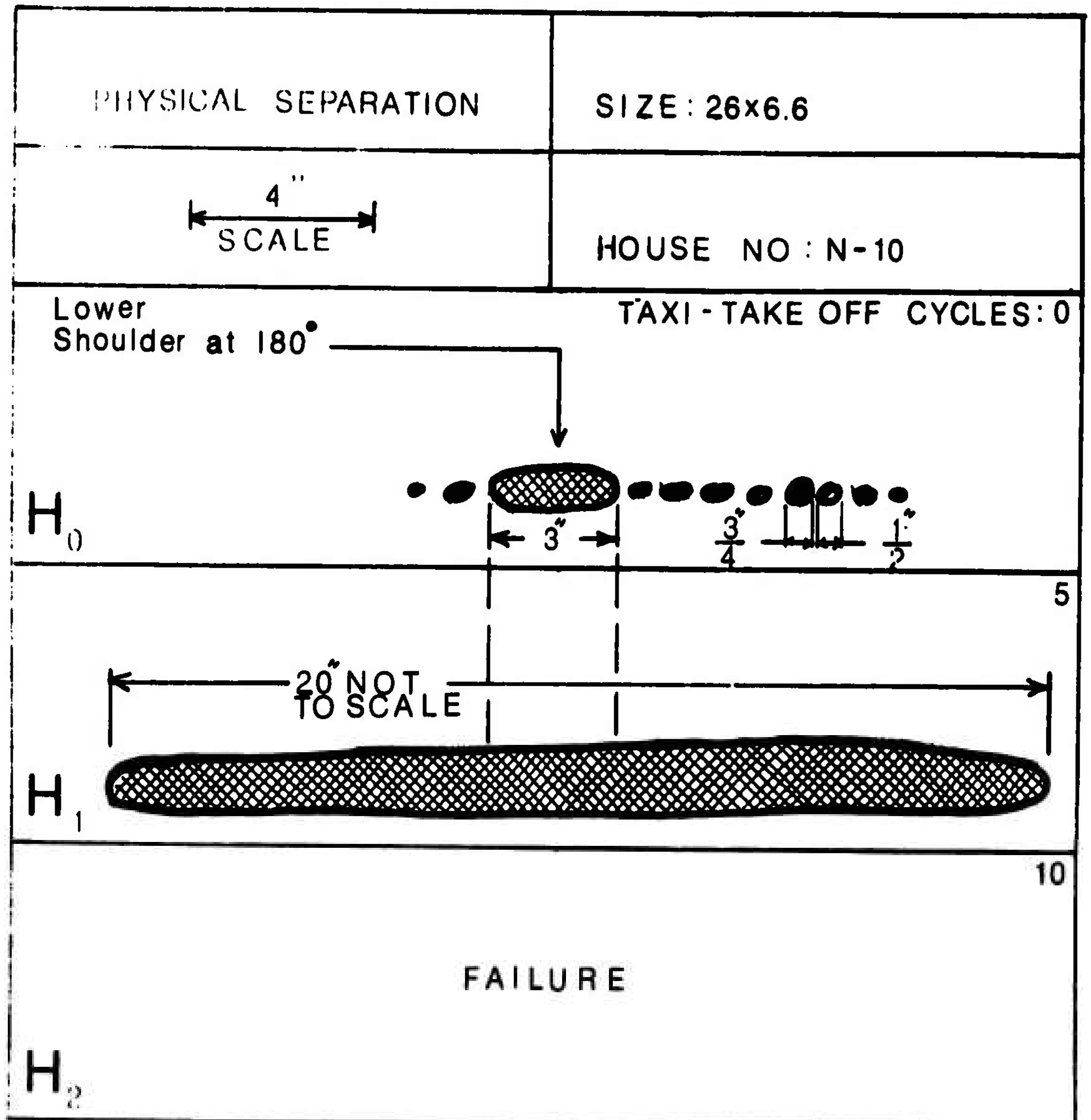


FIGURE 22.a.
U.S. Navy Tire No. 7 – Indoor Test Wheel

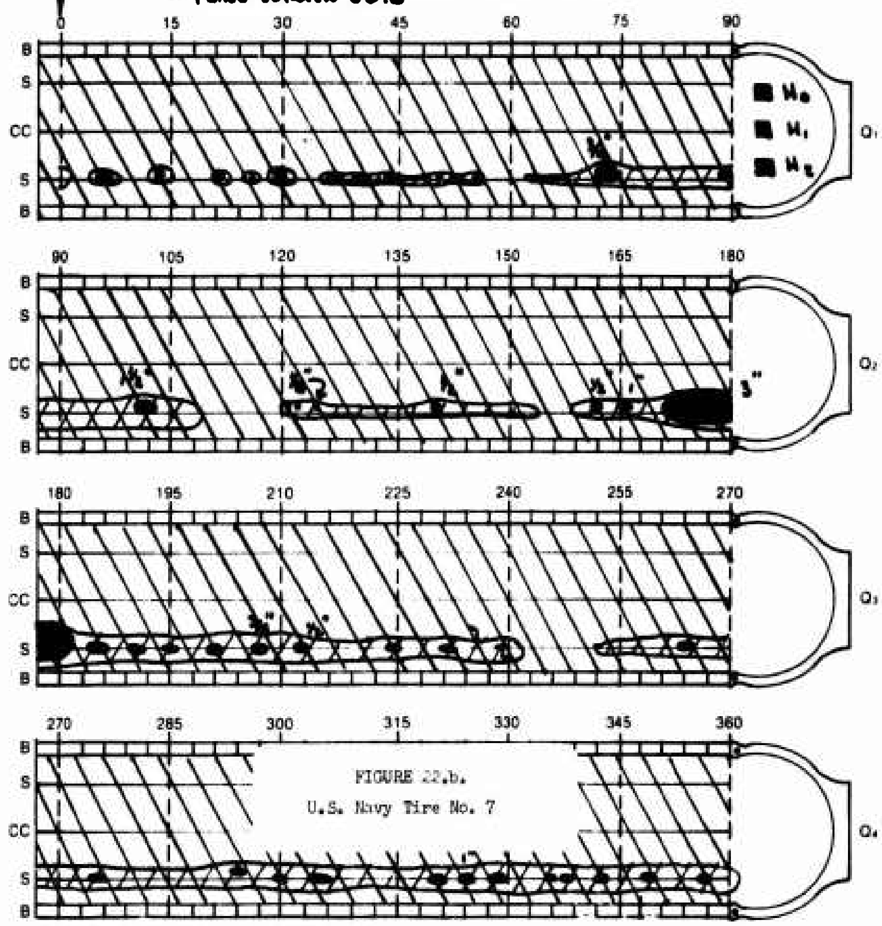
Failed Σ_0 Σ_5 Σ_{10}

IHI
LABORATORY REPORT

Customer	Tire O K / Special Study / Reject	Size	House Number
NAVY	Special Study ✓	26x6.6	N10
Mileage	Retread Number	Carrier In / Out	Serial Number
5+	R1		1280AK0873
Date Received	Date Shipped	Shipper Number	Holograph Number And Date: H0 11/26/74, H1 3/1/75, H2 5/15/75

Serial No Up

Failed between 5&10



B bead S shoulder CC crown center

FIGURE 22.b.
U.S. Navy Tire No. 7

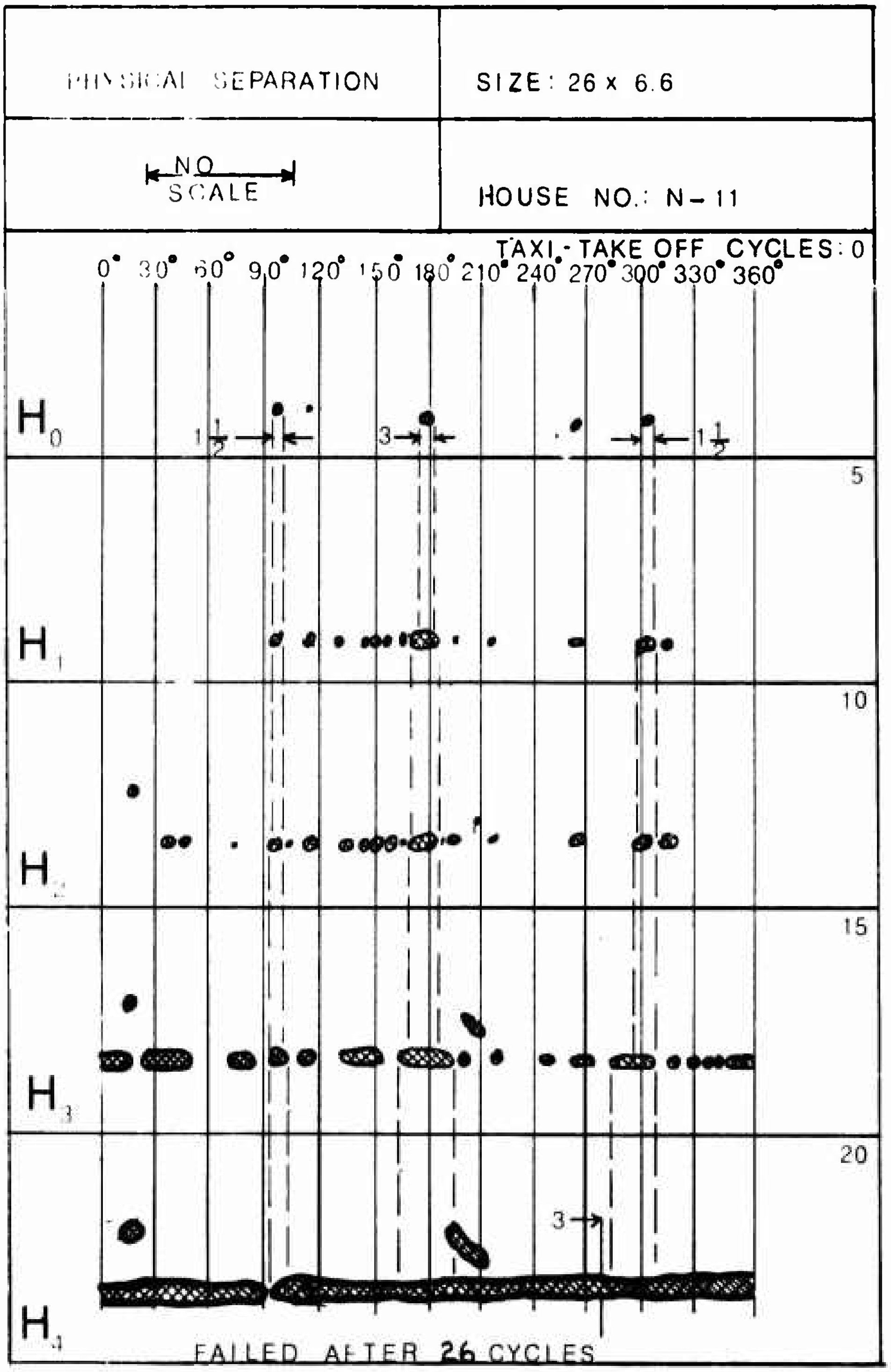


FIGURE 23
U.S. Navy Tire No. 8 – Geometrical Clustering

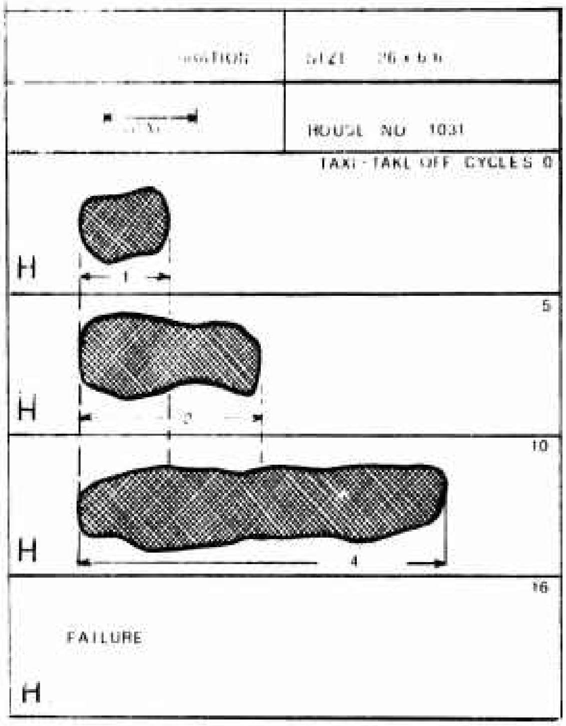


FIGURE 24
U.S. Navy Tire No. 9 –
Typical Geometric Propagation

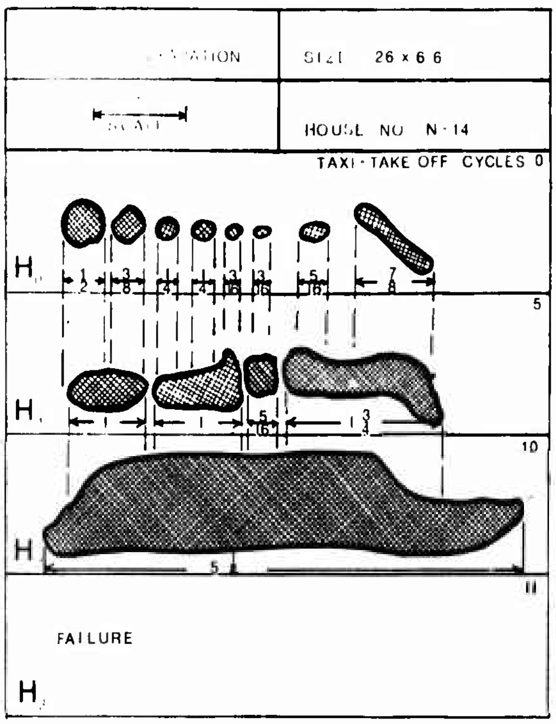
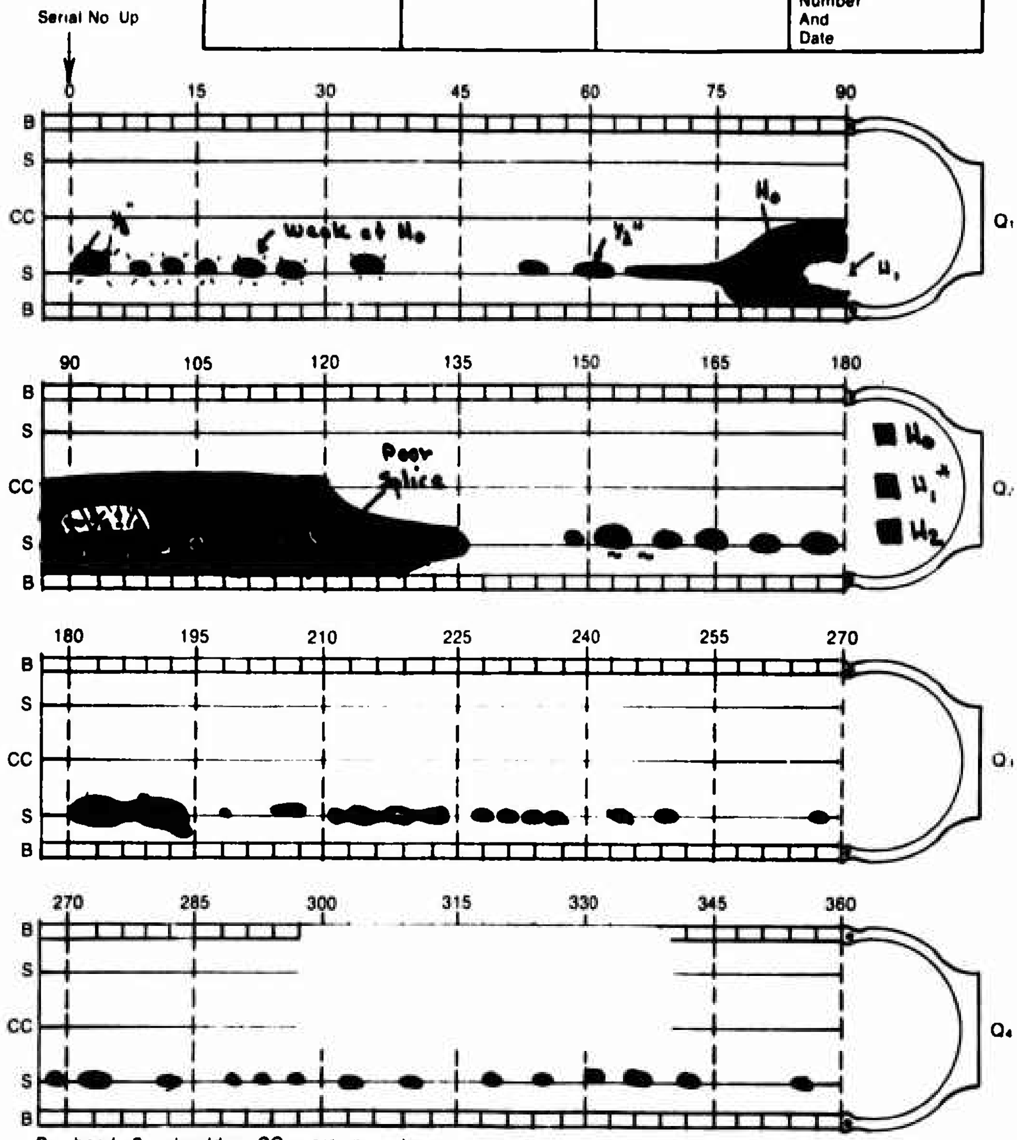


FIGURE 25.a.
U.S. Navy Tire No. 10 – Propagation Pattern

Failed Σ_0 Σ_5 Σ_{10}

IHI
LABORATORY REPORT

Customer	Tire O K / Special Study / Reject	Size	House Number
NAVY	Special Study ✓	26x6.6	N14
Mileage: 15 T.T.'s	Retread Number: R_1	Carrier: In / Out	Serial Number: 211SAK0281
Date Received	Date Shipped	Shipper Number	Holograph Number And Date



B = bead S = shoulder CC = crown center

FIGURE 25.b.
U.S. Navy Tire No. 10 – Test Chart

*Not all H_1 data has been inserted due to complex structure.

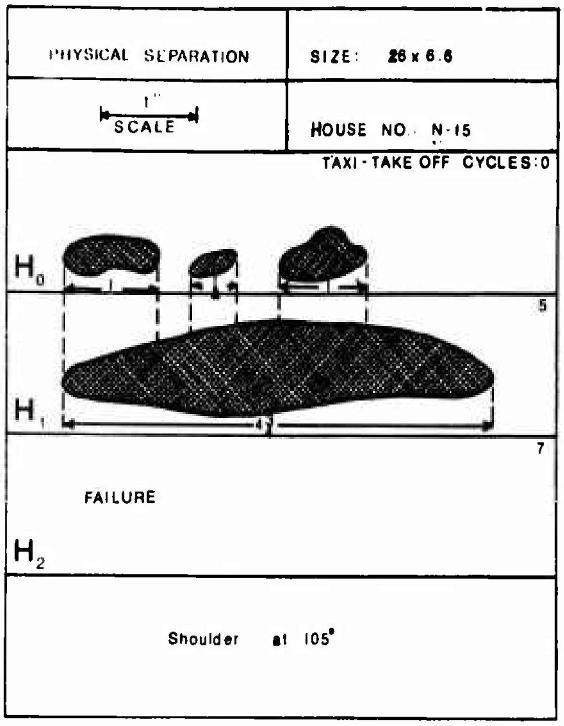


FIGURE 26
U.S. Navy Tire No. 11 – Propagation Pattern

One control tire for this group, Tire #12, which was a strong, structurally uniform tire showed no signs of deterioration after running through the same number of cycles as those discussed above.*

This type of data could be given in greater detail for a large number of examples, but it represents the typical type of information that one obtains on an indoor test wheel. Needless to say, high quality "control tires", observed holographically, ran beside these without mishap. (In a number of cases, as an aside comment, we have predicted the success or failure of tires being sent through conventional qualification tests required by the Navy.) In summary, we can say that when separations exist in a 26 x 6.6 aircraft tire in the size category of ½" ±¼" category, it will go through a significantly larger number of cycles (25 to 50) before it goes to failure if the carcass possesses a high degree of structural uniformity. Digressing momentarily, the author would like to point out that more detailed studies should be carried out on adhesion levels and porosity, which are observable by holographic procedures. Note, for example, the photograph (Figure 27) which is a typical case of heavy porosity caused by undercure as confirmed after the hologram was taken by cutting the tire's center crown.

On the other hand, note Figure 28, which reveals via the holographic pattern a reduced adhesion level in two regions of the tire. These regions were caused by a latex based marking substance which was not absorbed by the com-

*In future test work, a larger number of high quality test tires should be run out to failure.

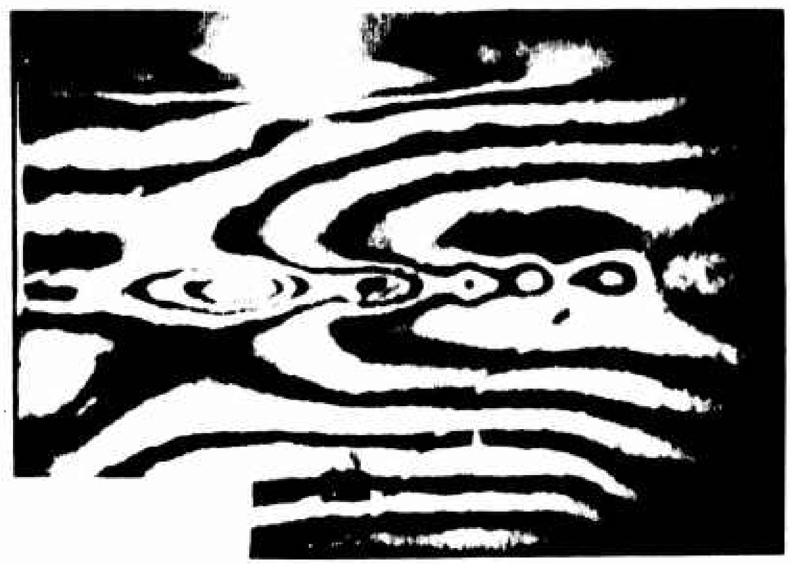


FIGURE 27
Pososity in Center Crown Region

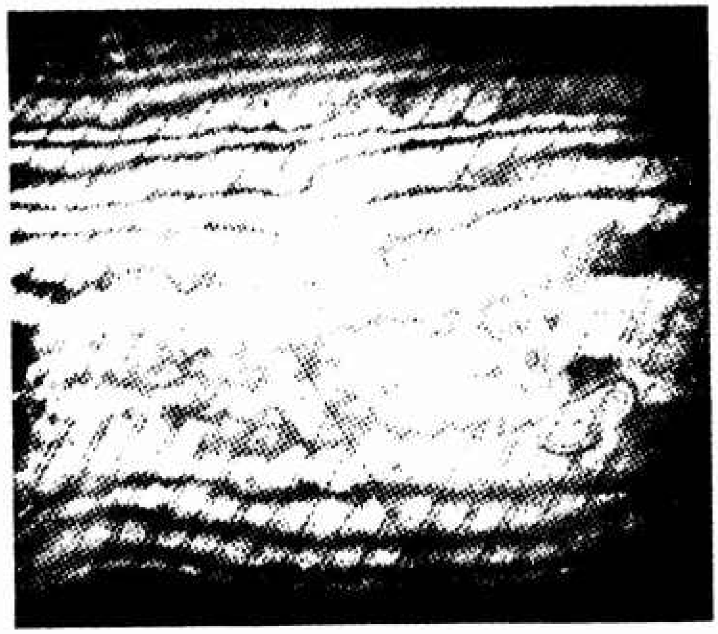


FIGURE 28.a.
Holographic Pattern Revealing Low Adhestion
— Courtesy of C. Hoff, B. F. Goodrich

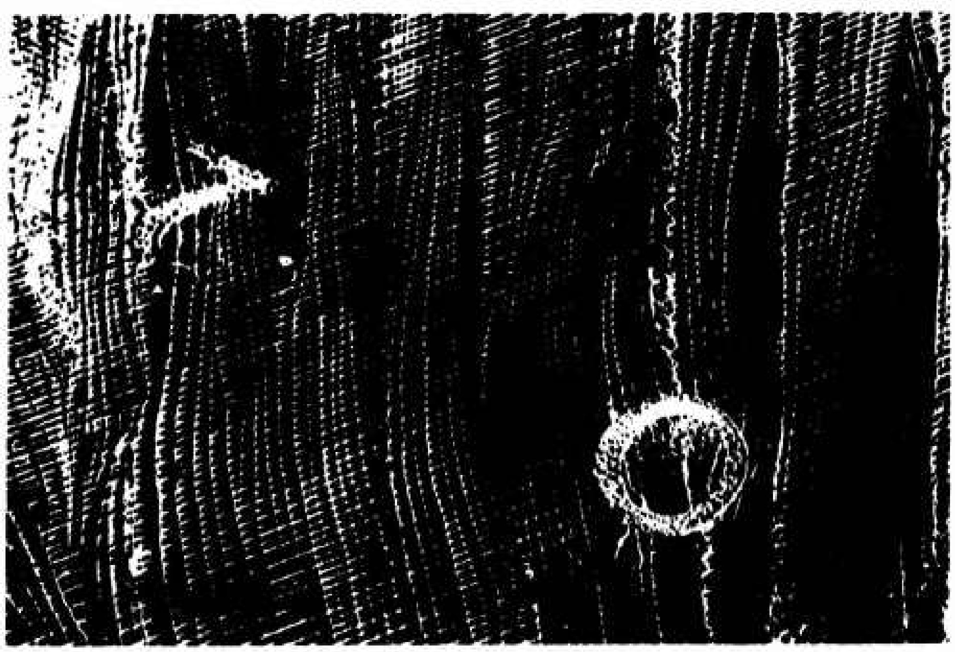


FIGURE 28.b.
Physical Tire Dissection — Tread to Carcass rubber surface revealing latex based marking substance which reduces adhesion levels.

pound (marking substance used to record date codes on the fabric). Note the reverse number "20" which resulted in lower, "non physically separated", adhesion levels as revealed by the physical sample shown.

Before proceeding, mention should be made about the percentage of rejections as a function of a given R level for commercial aircraft tires. We have found throughout our statistics that roughly speaking the same percentage of rejections, plus or minus 10%, take place at each R level in large distributions of 40 x 14 - 21 aircraft tires. This data would suggest that separations are appearing at each R level at about the same rate. Separations continue to appear as the cords loosen up and general fatigue sets in. Much of the data which we have observed to date in 40 x 14's would suggest that one would be wise not to make the decision to reject a tire based on a given R level. It would appear to be a much wiser criteria to decide on the life of a tire based on the number of cycles or landings it goes through rather than the number of R levels. This is the data which must be obtained in the future. We strongly feel at this time that once an understanding is obtained of the degradation of a carcass as a function of the number of landings that decisions should be made wherein a tire is allowed to stay on an aircraft as a function of the number of landings and not as a function of the number of R levels. It is conceivable that a tire with an R level of, for example 5 or 6, could have significantly less landings on it than another tire which is only an R-2 or R-3. This could partially explain the reason why we sometimes see less fatigue in an R-5 or R-6 than we might in an R-3 or R-4.

Next we note in terms of failure mechanism characteristics of a given tire construction that the small separations propagate very slowly if they are in a very strong tire and that these separations will propagate out through a number of landings before the background carcass begins to weaken, to loosen up, and then go to terminal failure over a fairly short number of landings. Now let us compare the above notation very briefly to truck tires whose separation propagation rates are well behaved. If we were to look at separation size as a function of mileage and draw a graph for truck tire data, we would notice that it would fall very nicely along a given line. In general, the relationship between separation size and mileage is a linear function with the variation in slope of that line being determined by the overall strength of the tire. In the case of truck tires, we then have a band of linear traces whose milder slope represents tires which are quite strong. Those linear traces with a stronger or higher slope represent tires which are weaker.

When measuring aircraft tires, we think in terms of the number of taxi-take off cycles versus separation size. Here, we notice that a small separation will typically propagate in a strong tire slowly wherein the curve along which it travels (that is the separation diameter as a function of cycles) will look very much like the truck tire case. After many cycles, and after the carcass has begun to fatigue and loosen up, there will be an increase in separation size as a function of cycles which will increase exponentially to the terminal failure point. In a tire which has a very weak carcass, we will note that the separation size will increase exponentially as a function of the number of cycles in very early stages, whereas mentioned above, the separation size as a function of a number of cycles will increase linearly with a very mild slope for a long period of time and will then rise exponentially in a strong tire. As mentioned earlier, the cardinal difference between truck tires and aircraft tires is the following point. Almost without exception, all separations or areas with a high probability of separation will be observed in the original carcass at the time the tire is new. Even after the tire has been retreaded new separations are unlikely to appear in a radial truck tire unless they are the result of mistakes the retreader has made. New separations which are specifically a function of the carcasses themselves do not appear at these later stages. Conversely, in the case of aircraft tires, the separations which are observed at various periods during the life of a given aircraft tire carcass seldom appear when the tire is new or straight out of the mold. As a matter of fact, on the average, rarely does one see in new aircraft tires more than 1% or 2% which are separated. On the other hand, after a number of cycles, perhaps 1000 landings which may be at a R-5 level, one might note a number of separations in a given tire carcass which did not appear either at the early stage of the tire's life, or in the previous R level. In other words, separations continue to form and propagate (note Figure 29) at a variety of stages throughout an aircraft tire's life (throughout each of its R level stages). It is not uncommon to see no separation in a R-0 level of a given tire, or its R-1 level, or its R-2 level and on up to some R-n level whereupon separations will appear over a very short period of time and with great profusion. When establishing acceptance-rejection criteria, this would lead one to the conclusion that aircraft tires must:

(A) be studied to determine the type and location of separation which will form and the average rate of propagation of these separations. The rate of propagation is by far the most significant parameter for a given tire.

(B) be studied to determine the type of failure mechanism which is given construction experiences. Furthermore, it is evident that the tire must be tested intermittently after a given number of landings. In the case of 40 x 14 - 21, the number of landings associated with a given R level, for example from R-1 to R-2 in a typical DC-9 operation, turns out to be just about the ideal spacing for the frequency of testing.

(C) be studied by holography before and after each R level to determine the optimum number of landings for a given size, construction and manufacturer. In the future, this test time can be

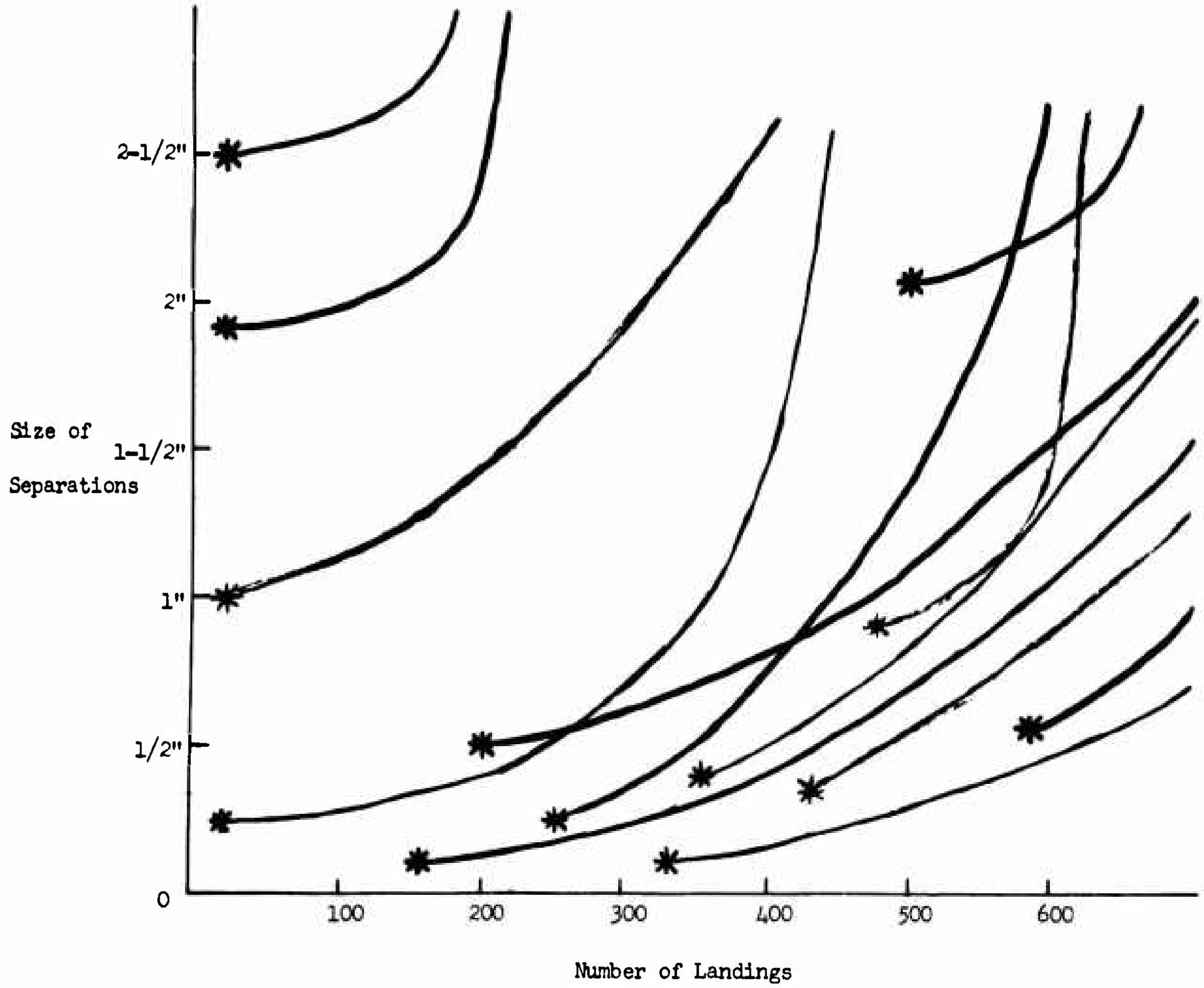


FIGURE 29
General Separation Propagation Behavior As a Function of the Number of Landings

established as a function of the number of landings a tire experiences, provided that the inflation pressure has been maintained throughout the period under consideration. Note: Underinflation will significantly increase the propagation rate of separations. If a tire reaches an established number of landings, it should be retested prior to further use.

The following information is the result of our first commercial carrier studies which were carried out over the past two years. This carrier was experiencing approximately one tire failure per month over a one year period with an average cost per failure (amortized over the year) ranging between $20,000 and $25,000, due to structural damage to the aircraft and rubber ingestions in the engines. Over a relatively short period of time, all the tires in service of a given type were holographically tested and all tires with separations greater than one-half inch in diameter were rejected. Since the tires with separation over one-half inch were taken out of the systems, no tire failures were experienced over the following two years. It is important to note that this type of testing will not eliminate all tire failures, but it can significantly reduce the incidence of failure which has been dramatically proven in more than one airline. It is interesting to note that the original rejection rate in the above case was slightly over 20%, whereas after culling out the tires containing separations over one-half inch in diameter, the rejection rate fell to around 12%. Further analysis has revealed that larger separations can be tolerated in the crown area which puts the rejection rate under 10%.

Now to summarize. The basic objective of this paper has been to comment upon the meaning of separations in aircraft tires. You can look at sizable distributions of tires and discover that large distributions of tires have very low incidences of separation – at times as low as 1%. Then we will note other case histories where the percentages can get significantly over 10%. Our basic objective at this time is to understand more thoroughly the background strength criteria in aircraft tires and to establish an acceptance-rejection criteria based on a fairly large data base. In general, we would like to test 1000 tires in a distribution and then cull out those tires which have separations. The tires pulled out must be evaluated to determine separate propagation rates as a function of structural uniformity. Acceptance-rejection rates should then be established and then routine testing of the tires should be carried out at each R level where the R level does not exceed a given number of landings for a given tire size and construction. It has been said, "Well, you see most separations in retreaded tires; you don't see many of them in new tires." This is a misleading statement. Although separation typically does not exhibit itself until an advanced stage in a tire's life, the original construction and the care with which the original tire is built has a significant impact on the amount of separations which will appear in the tire's later life. Needless to say, we find that retreading practices are not often the cause of separation in aircraft tires.

It is only going to be with the greatest of effort and patience that the separation propagation rates and basic failure mechanisms are understood whereupon realistic acceptance-rejection requirements can be placed on a given tire despite the fact that relatively few tires contain separation. Although all tires experience fatigue as a function of usage which–if the tire is used long enough–will, in turn, eventually lead to separation. The general performance of the typical aircraft tire far exceeds that of most typical engineering systems. Aircraft tires perform an extraordinary job in terms of the requirements that are placed upon them and the abuse given to them. With modest effort, great improvements can be made in aircraft tires at relatively low costs resulting in an example of one of the most impressive engineering systems of our day– namely, the typical aircraft tire.

Through the use of holographic testing, tire failure, which can result in expensive aircraft damage, can be reduced. The cost of these tests are relatively small as compared to the potential savings brought about by reduced failure incidence. Moreover, high quality tire carcasses can be used for a larger number of total landings than was previously realized.

ACKNOWLEDGMENTS

For information used in the presentation of this paper, the author wishes to gratefully acknowledge the assistance of:

The U. S. Navy (Principal Support)

The U. S. Air Force – Wright-Patterson Air Force Base

Firestone Tire & Rubber Company

Piedmont Aviation

Pan-American Airlines

Air Treads, Incorporated

Thompson Aircraft Tire Corporation

B. F. Goodrich Tire & Rubber Company

Sumitomo Rubber Industries, Ltd.

EXPERIENCE WITH TIRE DEGRADATION MONITOR IN COMMERCIAL APPLICATION

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A Subsidiary of GATX Corporation
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Experience with the TDM (Tire Degradation Monitor) in Commercial Applications

Several years ago at the Second Symposium on NDT of tires in Atlanta GARD and the U.S. Army[1] presented the first of our results on ultrasonic testing of tires. That presentation gave the description of the genesis of the tire degradation concept and road test results that verified the concept with military tires. Bob Watts of TARADCOM will in a later paper at this symposium present a more detailed look at the Army program—past, present, and future. Again at the Third Symposium we provided updated results of testing of the degradation concept and associated tire research. Now at the Fourth Symposium we are going to present our further experience since the Third. I am going to emphasize the commercial use of the TDM and Bob Watts will talk about the military use.

First I feel it is appropriate to review the concept of tire degradation and its development. The original intent of our Army sponsored research program was to develop a NDT means of inspecting tire casings prior to retreading. We concentrated on ultrasonics because of its potential for speed, automation, sensitivity, and low operating costs. We looked at two basic approaches: through-transmission and pulse-echo.

The through-transmission had a number of potentially significant advantages. It was air-coupled (no direct contact with the tire would be needed) and it operated at a frequency (25 - 40 KHz) which seemed to be good for the size of defects of interest. It has one serious technical drawback which in the end dictated against its use. That is an inability to know the distance to the defect. Thus, a tread lift or separation looks the same as a ply separation; patches can look like separations; a nail hole in the tread rubber may look like it penetrates the body; and cuts in the tread will look like cuts in the plies. The lack of distance information is the fundamental reason why we dropped further research with the air-coupled through-transmission technique in favor of water-coupled pulse-echo.

Water coupled pulse-echo has two fundamental advantages: sensitivity and distance information. Its fundamental disadvantage is that it needs to be directly coupled into the object of inspection. The direct coupling generally is done through a liquid medium (in our case, water or a water soluble compound). Our first attempt was a 360° scanning machine shown in Figure 1. (We have built two of these machines and both are currently in use at Army Retread Depots.) We scan the crown and shoulder areas of each tire.

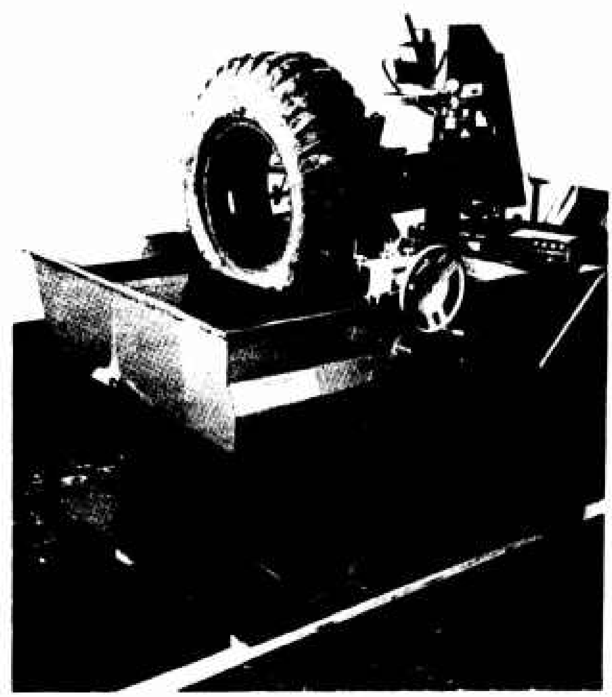


FIGURE 1
TIRE SCANNING MACHINE

After completion of a rather extensive (500 tires) program of tire inspection with the UT scan system and in conjunction with other tire research we developed a rather unique

1. "Ultrasonic Tire Inspector", Gamache and Kraska, Proceedings of the Second Symposium on NDT of Tires, NTIAC 75-1.

concept of a fundamental mode of tire failure—degradation. Our research indicated that as a tire was run its background ultrasonic character would continuously change until a failure occurred (Figures 2 and 3). We correlated this change first with a reduction in cord and peel strength and finally with road test failure.

We hypothesize that as a tire rolls and is fatigued in service the cord structure begins to break down—particularly in the outer plies. In a steel-belted tire the cords are basically inextensible and the break-down occurs typically between the steel belts and the body plies. (In fact even in fabric-belted radial tires this seems to be true—thus giving rise to the common belt-edge separation.) Retreaders know this degradation by the term "casing fatigue" and see it also as casing growth or stretching on fabric tires. A number of other different researchers have apparently observed this phenomenon without realizing it. It can be seen as exces-

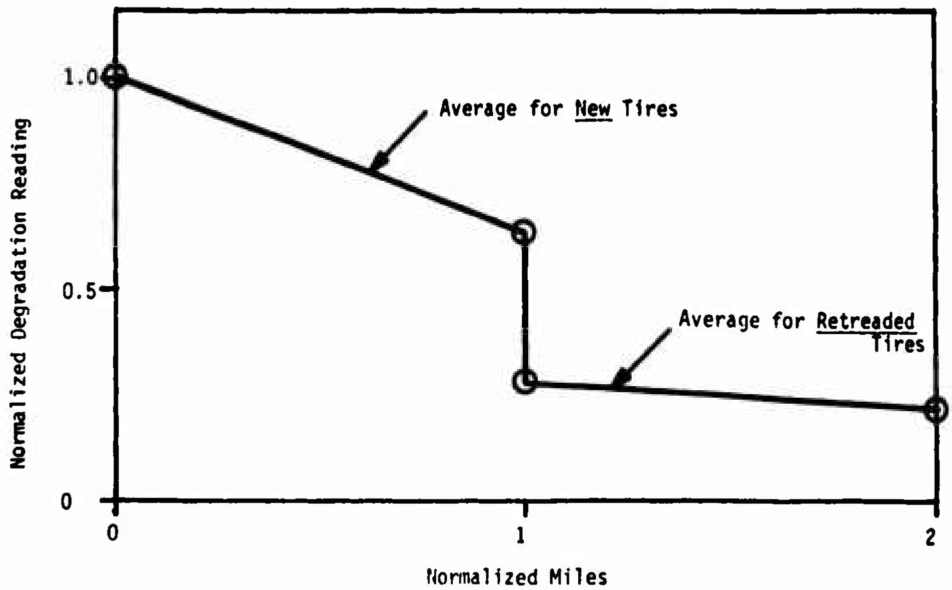


FIGURE 2
POPULATION DEGRADATION READINGS

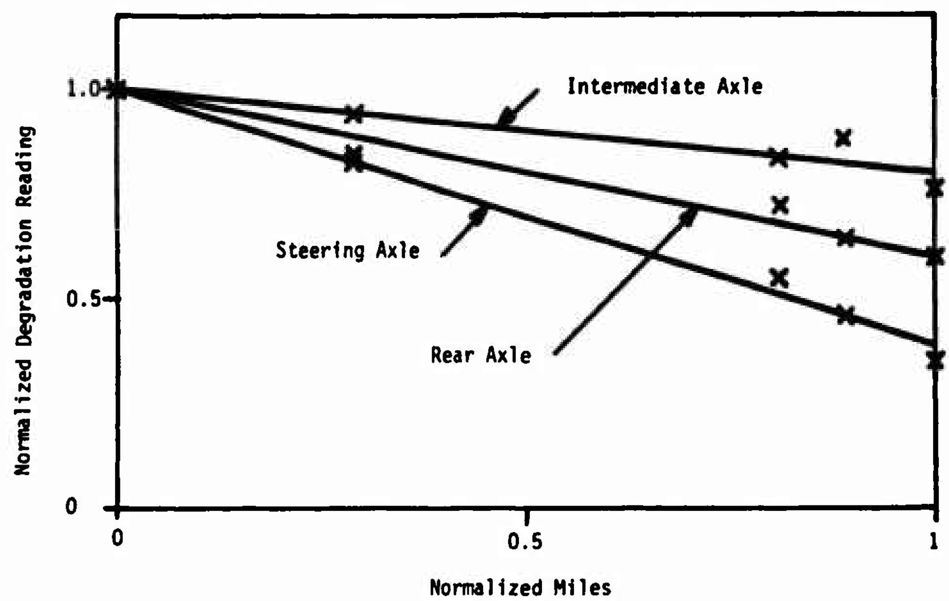


FIGURE 3
ON-VEHICLE DEGRADATION READINGS

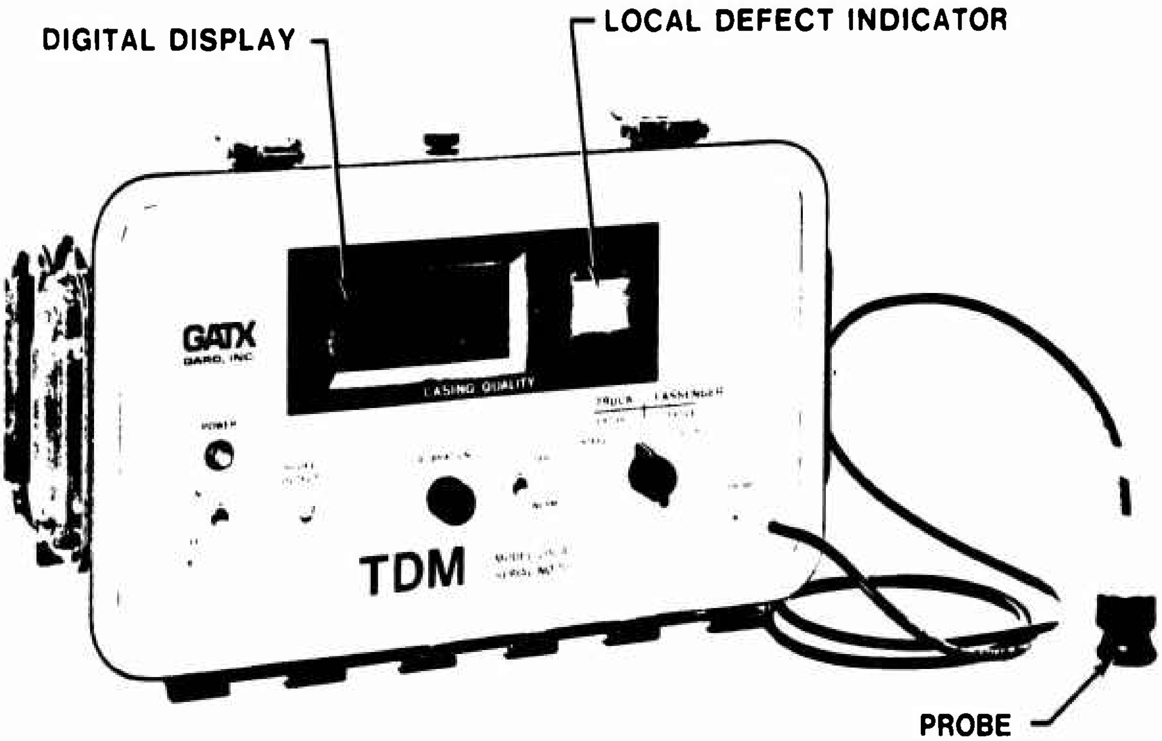


FIGURE 4
TIRE DEGRADATION MONITOR

sive attenuation in air-coupled UT, excessive absorption of air or radioactive gas in variations of the air needle injection test, and a fringe waviness in holography.

The fact that the UT degradation measurement correlated well with road test failure led GARD to develop and introduce the TDM (Tire Degradation Monitor) as a simple economical means of estimating residual casing life prior to retreading. The commercial version is shown in Figure 4. Selling the UT concept to an industry that until this time has not really utilized ultrasonics has been a difficult task. First there is an expectation that if an NDT device is to be of value it must cure all problems at once—which, of course, no NDT device is going to be able to do on a structure as complex as a tire. Secondly, it is expected to be totally fool-proof as the industry apparently feels it has almost no control over its work force. And lastly, it must be very inexpensive.

Surprisingly, we feel that the TDM comes close to doing all of these things—except find every type of tire defect. Still it has been a slow education effort that is beginning to show a number of excellent results. This is a tribute to the people who have bought a TDM, devoted some time to learning its operating principles and how to use it. We have found that the users who made an effort to understand the TDM and use it on a consistent basis have a very high regard for its usefulness and value. Those people that dabble at it get very confused and are less convinced of its value. For our part we underestimated the time it would take for people to become used to using the TDM and the general need felt by our customers for the CRT presentation of the signal in addition to the digital display. Small inexpensive, ($400) readily available scopes can be used and have been supplied to most of our customers (the others supplied their own scopes).

The main intent of this paper is to acquaint the tire industry with some of the commercial applications to which the TDM has been put and this I will now do.

One of our earliest applications was inspection of nylon truck tires for undercure. Undercure in a new or "hot-cap" type of retread is generally indicated by porosity formation in the shoulders (Figure 5). The TDM used with a scope can be used to detect this porosity and hence undercure. Figure 6 shows photographs of the scope traces for both properly cured and undercured tires. The signals at the far right of the undercure trace indicate porosity whereas normal tires are clear in this area. All of this inspection

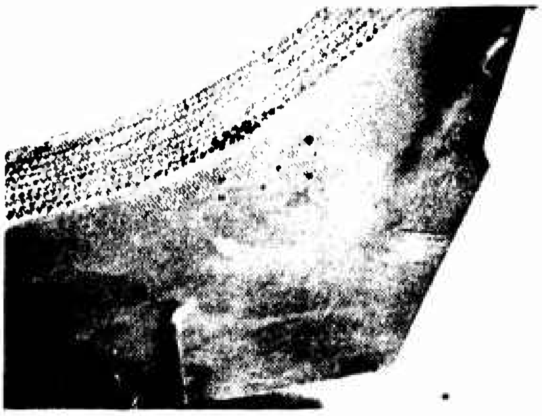
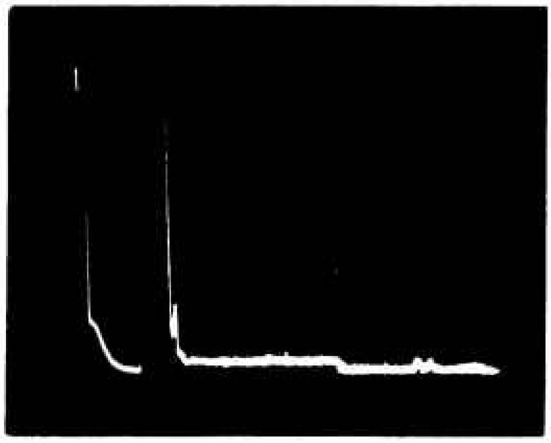
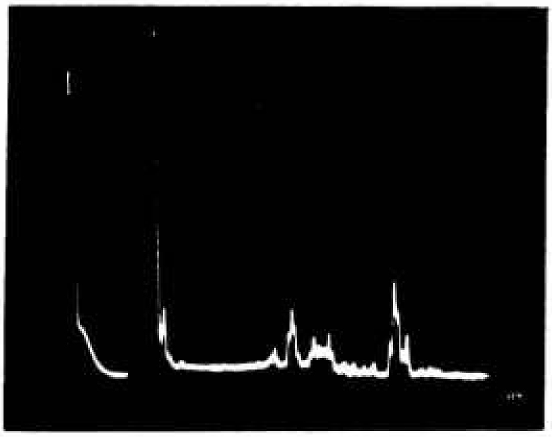


FIGURE 5
CROSS-SECTION OF UNDERCURED TIRE



a. Normal Tire Cure



b. Undercure

FIGURE 6
SCOPE TRACE – UNDERCURED TIRE

was done from the shoulder. The digital display is not used. Figure 7 shows inspection being performed in the tire plant. Note that tires are being inspected in stacks so that tire handling is minimized. This capability is unique to pulse-echo ultrasonics. The result of our inspection of approximately 700 tires was that approximately 70 undercured tires were found which agreed well with the manufacturer's expectation. The alternatives would have been very expensive radiography or scrapage of the whole lot of tires. Estimated cost savings: $4000 up to $70,000 depending upon ability of radiography to see minor porosity in truck tires.

Two of our earliest sales of production units went to two Bandag dealers: American Bandag of Libertyville, Illinois and Weirton Bandag of Weirton, W. Virginia. American inspects all incoming casings with the TDM for grading and sorting. Originally they followed our suggested guidelines (Figure 8) which initially caused distribution of tires as shown on Figure 9. As American has gotten more experience they have instituted a much more complex disposition procedure. Their current disposition grading scheme considers such things as customer (end use), size, tire construction, and tread thickness to be applied to the tire. The TDM readings are the key to this scheme and are recorded in the tire invoices, and stored in their warehouse computer memory records for future data analysis.

An example of the system's usefulness came when one customer complained of top ply separations after only several thousand miles of running. Knowing that the tires had been graded and had been selected to be good casings for drive wheel use, the plant manager, John Nelson, looked either for processing or use errors. It turned out that the customer had used the tires on single drive-axle tractors which apply a great deal of torque to the drive tires. American backed off to a lighter tread to minimize heating and flexing problems and has had no further complaints from the customer. In the pre-TDM days there would have been a considerable tendency to blame the casings until a great many failures had occurred. Another example of use is on steel radial truck tires. They had prior to TDM use experienced a large number of retread failures of tires from one manufacturer. They (and a number of other retreaders) were about to put a halt to retreading of that type of tire when they started to examine the tires with the TDM. A

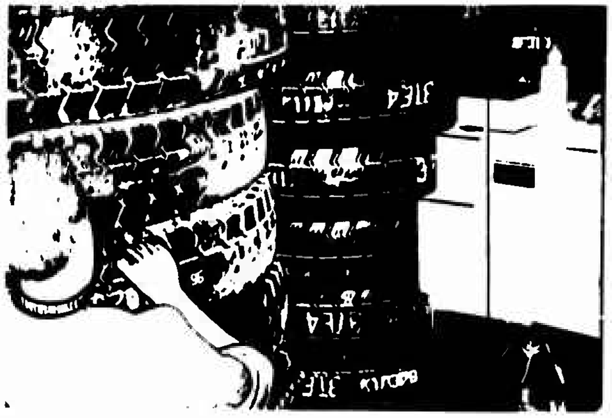


FIGURE 7
TDM INSPECTION IN PLANT

TYPICAL TDM CLASSIFICATION
(TRUCK TIRES)

TDM Reading Range	Disposition of Casing
0-1	Reject
2-4	Trailer Use Only
5-16	Any Use
17-25	Trailer Use Only
Erratic	Trailer Use Only
Red Light	Trailer Use/No Warranty

FIGURE 8

INSPECTED TIRES

DISPOSITION	DISTRIBUTION %
Reject*	4
Trailer Use	46
Any Use	50

* This rejection is before normal visual inspection

FIGURE 9

great many of the tires were found to give a very high reading. (Such tires are called "red-light" tires because the reflected signal is so high as to trigger the separation indication light.) American held back the "red-light" tires and retreaded the rest with their heaviest tread. Result: no further failures of these tires.

"Red-light" tires are a small but significant portion of the tires that come into American. Certain classes of these tires have been found to be non-retreadable, while others seem usable for light duty use. At first some customers complained about holding out tires based upon TDM readings, but most have become convinced about or at least accept this procedure. An adjustment avoided by the retreader is a down-time incident avoided by the vehicle owner—both save money.

American says they will not retread tires without a TDM inspection. They have inspected almost 20,000 tires with the TDM, and have it running 8 to 10 hours per day. After some early electronic "bugs" were corrected, reliability has been 100%. The use of the TDM and other on-going quality control improvements have reduced adjustments from near 5.6% two years ago from all causes down to 1.8% currently with records being kept by computer—not based upon general impressions. The 1.8% figure is very good while maintaining a very high rate of casing utilization (80%) and is a good customer selling point. Their John Nelson says that while he can not develop an exact savings produced by the TDM it has greatly more than paid for the cost of the TDM and that they would not be without it.

Weirton Bandag does not use this machine on an every tire basis, because as R. Rock, Retread Foreman, says: "We learned so much about visual tire inspection the first two months we had the TDM, I feel we do not need it for normal use because we can fairly accurately guess the TDM reading". They now use the TDM only on questionable tires, but very much believe in the TDM and the degradation concept. They too have moved away from the original grading scheme to one tailored to each of their customers unique requirements. They too have shown customers that certain manufacturers or types of "red-light" tires can not be retreaded even though visually the tires look perfectly good. (The high level UT reflection is generally from the first ply or the bond between the undertread rubber and the tread rubber. In many cases we have found a layer of microporosity to be the reflection; but in others we still do not know what causes this very high reflection. It should be the topic of some very interesting research.)

In a test run by a major rubber company 16 pairs of matched retreads were road-tested on trailers. One tire in each pair had a TDM reading of 3 or less and the other had a reading of 4-15. The results were that 80% of the low reading tires failed during the test while only 20% of the moderate reading tires failed. Further testing on dynamometers has not shown such consistent results; but it is our feeling that degradation failures are not well simulated on wheel tests because wheel tests do not duplicate the random fatigue loads that tires see in service. (Aircraft manufacturers have found, for example, that metal behavior under random loading is considerable different than under a uniform cyclic load.) We recommend using road tests.

A number of interesting uses have been developed using the TDM as a quality control device. The major rubber companies, large retailers, and consultants have been active in this area. The use of the TDM to detect undercure in truck tires was mentioned earlier, but it has also been shown to work well on passenger tires as well (using shoulder inspection and a scope). One rubber company is using the TDM as a means of checking for undercure and microporosity in one of their retread plants. Searching for microporosity one generally uses the scope although an experienced operator can probably do it with the digital display only. Figure 10 shows a schematic of what one would expect to see in the scope trace to find undercure. Figure 11 shows some actual scope traces of microporosity (as noted by indication of a poor retread bond line) versus no microporosity layer in a good retread bond.

Another rubber company has been using the TDM to monitor the development of belt-edge separations in aramid tires. The tires are checked every 2000 miles of road testing. They are inspected in the shoulder (at the belt edge) and the crown using the scope. The development of shoulder separation has been shown to coincide with changes of the tire monitored in the crown. It is our feeling that this

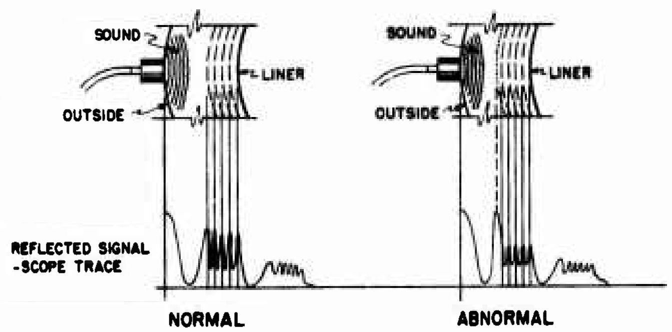
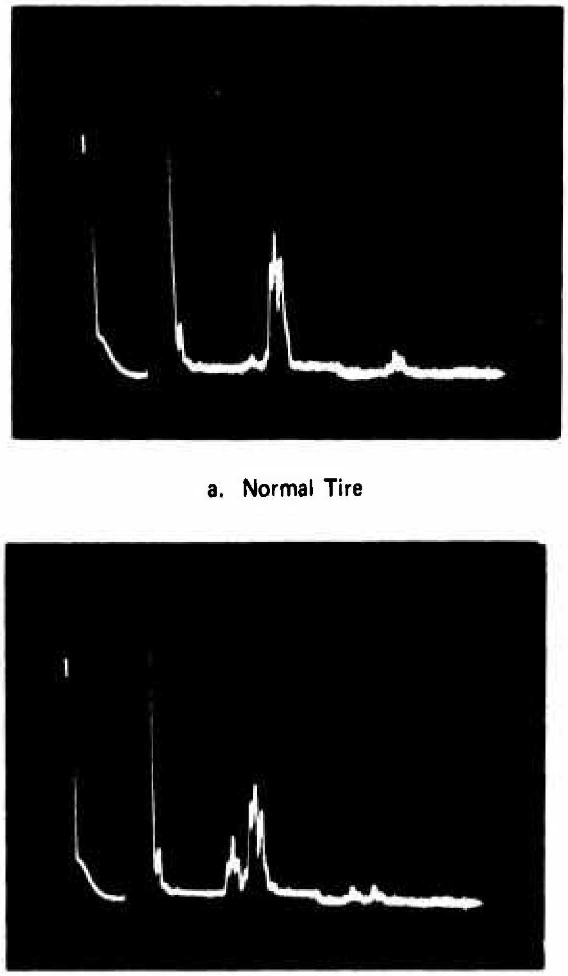


FIGURE 10
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE WITH INCORRECT TIRE – UNDERTREAD MICRO-POROSITY



a. Normal Tire

b. Bad Bond - Mircoporosity

FIGURE 11
TDM DISPLAY OF MICROPOROSITY

agrees with our earlier studies of radials in which failure occurs in the area between the belts and the body plies. How this change would be expected to look for steel radials is shown in Figure 12. The signal from the belt plies remain constant, while the signals from the body plies change. The radial setting on the TDM is set to read in this area and monitor this change, but the scope should be used to check to see that the gate reads in the correct location for differing types of tires.

A series of tests(1) performed on the West Coast on a fleet using radials also yielded information on belt-edge separations. In this case the inspection was done in the shoulder area because sectioning showed that the belt edge was directly underneath the outer rib and the surface plane was parallel to the plane of the plies at that point. Belt-edge separation caused a reflection to appear between the body and belt plies and a drop of reflection from the liner. Destructive sectioning of the tires indicated a 100% agreement between ultrasonic prediction and existence of separations. Partially as a result of these tests the fleet owner made a change of tire supplier (a multimillion dollar contract).

We performed some laboratory work on belt-edge separation detection and have shown it to be feasible. The key problem is knowing the location of the belt edges or developing a correlation between between edge behavior and changes in the crown. It would seem that one gets beyond manufacturing causes of belt-edge separation, separations at the belt edges ought to be indicated elsewhere, and measurements elsewhere should lead to prediction of belt-edge separations such as in the case of the aramid tires.

Another use of the TDM in quality control has been as a detector of production mistakes. If one considers the basic nature of a tire one can visualize a number of possible construction mistakes–missing ply layer, wrong cord size or material in a ply, two cord angles coinciding rather than alternating as they should, plus a number of mistakes possible in the bead area. All of these mistakes can and do happen. Typical factory QC normally catches these mistakes on a sampling basis, but usually only after thousands of questionable tires have been made. Because tires are built in many locations in a plant and funnel together for molding (where the serial number is applied in batches) a mistake at one building station is mixed with normal tires from other building stations. The overall result is typically something like 5% of a suspected batch of tires are really incorrect, but the inability to tell good from bad may cause the scrapage of 100% of the tires–possibly more than $100,000 worth of tires.

Past research with the TDM has shown that the TDM can spot many of these errors and can be used to sort good tires from the bad.The current problem is that human pattern recognition by operators of varying experience can not do this 100% reliably with a 100% confidence factor. Figures 13-15 show schematically some of the type of characteristics we have seen for these anomalies and how they differ from the reflected signals from normal tires. Our currently experienced 70% to 90% reliability should improve with more operator experience at the plants and perhaps some more sophisticated signal processing. Considering the cost of production threatened by these errors we feel that a substantial research effort in this area would be warranted by the tire manufacturers.

Finally, a note about separations. The TDM can spot separations either by scope recognition (Figures 16 and 17) or by the automatic circuitry in the TDM which extinguishes

1. Results reported by Jim Weir, Tire Consultant, Los Angeles.

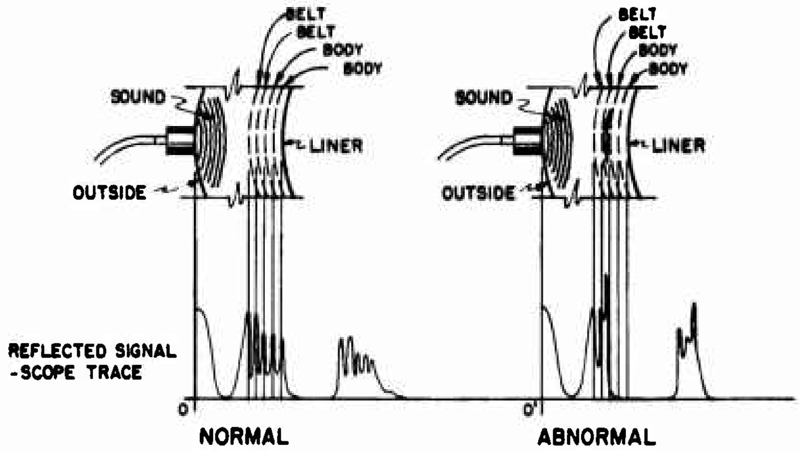


FIGURE 12
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
WITH INCORRECT TIRE – RADIAL PLY SEPARATION

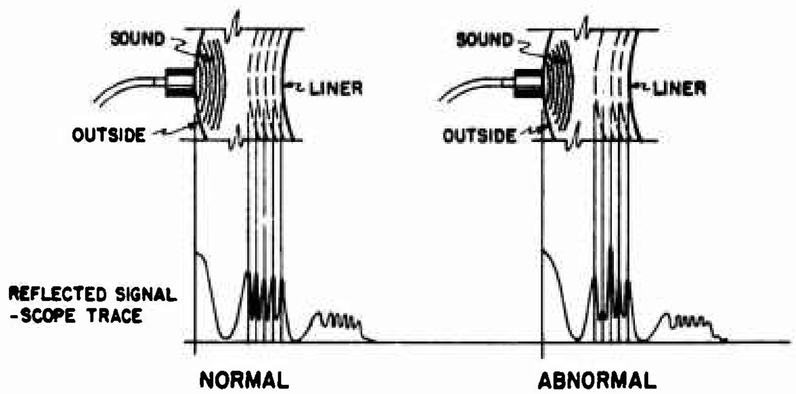


FIGURE 13
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
WITH INCORRECT TIRE – MISSING PLY CORDS – 2ND PLY

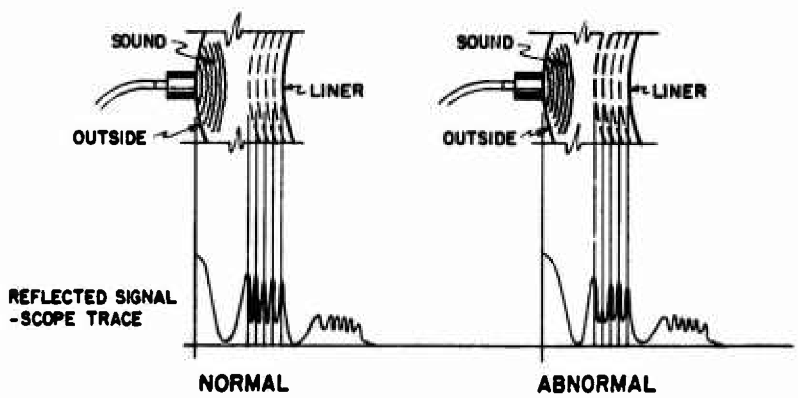


FIGURE 14
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
WITH INCORRECT TIRE – FIRST 2 PLIES WITH SAME PLY ANGLE

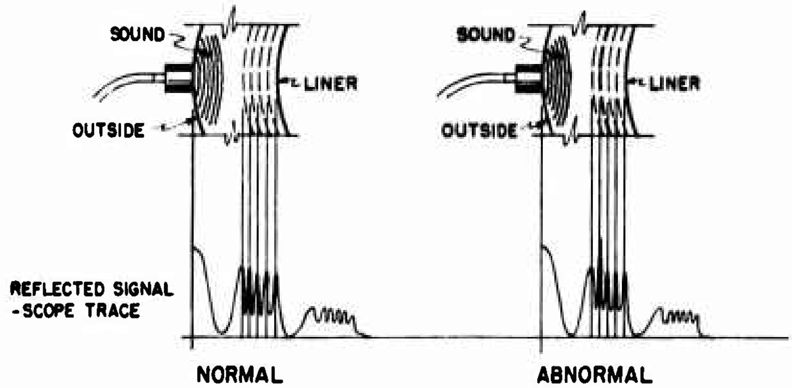


FIGURE 15
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
WITH INCORRECT TIRE – LARGE CORD – 2ND PLY

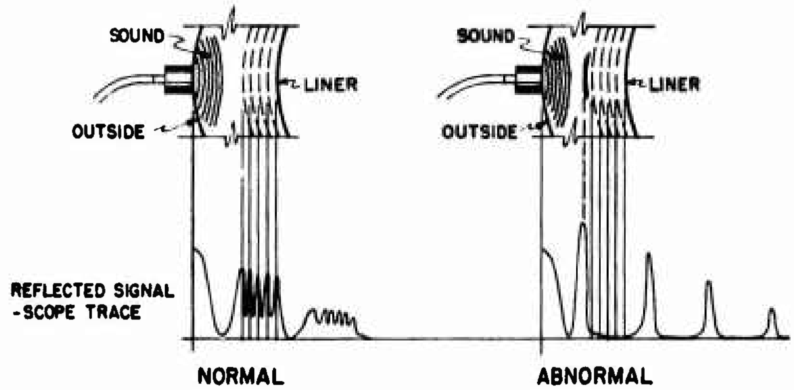


FIGURE 16
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
WITH INCORRECT TIRE – SEPARATION (UNDERTREAD TO TREAD BOND)

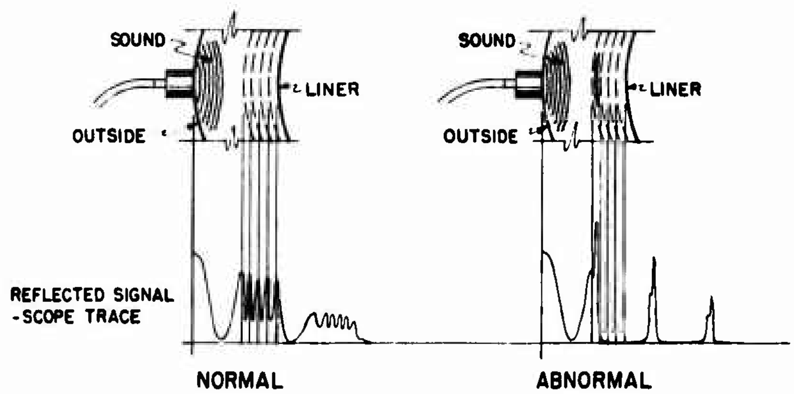


FIGURE 17
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
WITH INCORRECT TIRE – SEPARATION BETWEEN FIRST & SECOND PLIES

the digital display and activates a red light. ("Red-light" tires trip this light also without these tires having macroscopic separations. A little experience tells the operator how to distinguish between the two.) But it is too time consuming to search a casing by hand for separations and is not cost-effective. Using the TDM for casing fatigue measurement or QC on suspected areas or tires seems the most cost-effective.

GARD hopes that the tire industry (OEM and Retreaders) will continue to experiment with the TDM. It has an excellent potential to make a substantial improvement in reduction of road service tire failures – especially at a time when a great many radically different tire constructions are being tried, higher pressures are being used, and while at the same time a great effort is being made to reduce tire weight. Real-time NDT techniques that have the potential of being applied economically to 100% of a production run should be carefully explored. It is rather a paradox that retreaded tires can be 100% inspected by electronic NDT techniques at some facilities and yet most new tires are not. The pressure from the government on behalf of its own consuming organizations and the public seems to indicate more work will be done in this area.

QUESTIONS & ANSWERS

Q: With the present TDM, what's the maximum size it can work with and what does it cost?
A: The present cost of the TM is $5,850 and about $400 more to attach the scope. The question of tire thickness is somewhat a nebulous one. We have gone through about 12 to 14 plys for nylon truck tire. You can do thicker tires than that. We've looked at aircraft tires and we've looked at off-the-road tires. Our basic feeling is that for most tire construction the failures tend to occur in the outer plys and it's not very important to look at what goes in down in the lower plys. I know there are certain types of aircraft constructions where the tires fold back on themselves and get a lot of failures on the inside of the tire but for most tire constructions, failure does seem to occur in the outer plys so the thickness of the tire isn't very relevant. What you want to do is look at the outer plys and guess what's going on. They're the load carrying plys in normal tire construction.
Q: Do you feel now that you know what transducer and instrument electro-characteristics, frequency, pulse voltages are optimum?
A: I could not say that we've arrived at the optimum one, but we've arrived at one that we find works very well. The transducers that we have are specially made for us after quite a bit of trial and error type of work and do seem to work better than the normal, off-the-shelf transducers. These one megahertz transducers are specially built to work well with rubber tires. Beyond that, I'd have to refer to our ultrasonics expert, Irv Kraska, to tell you more than that.
Q: I was very impressed. But can you inspect for belt placement problems on radial tires, because it's very, very difficult with radial tires.
A: Well, with the TDM held by hand, I'm not certain if you'd know that you had a belt misalignment. You should be able to if you're talking about the runout and this type of thing, lateral runout, you might if you monitored at a fixture and move the tire underneath it to tell whether you had that. With radial tires I might have a tendency to do that with eddy current or something else rather than ultrasonics.
Q: You said here, I recall, that there were 4% rejected tires during inspection. Could you explain that figure?
A: That originally was 4% more than the retreader would normally reject beyond what they would reject for normal visual reasons. This would add to their rejection rate by about 4%. Actually, currently it's running less than that, probably only a couple of percent. What they have done during recent times is to use the casings that are graded to their best advantage. If you have a weak casing and you use it on trailers, then you are likely never to have any problems with it. If it's weak then you throw it out. Even many of these tires which originally were scrapped are now being put on piggyback trailers which never see any real abuse (all they have to do is hold air). So the actual rejection rate caused by the TDM is very, very low. It is important to note that they still do the normal visual inspection.
Q: Have you tried using different frequencies?
A: Yes, with the higher frequency you don't get as much penetration into the tire, with a lower frequency you tend to lose some of the sensitivity. We picked 1MHz to give us the maximum sensitivity and also an optimum penetration into the tire.

PNEUTEST: A radioactive tracer method for the evaluation of aircraft type quality before retreading. Method – Apparatus and performances.

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Section d'Application de la Radioactivité – CEA – SACLAY
FRANCE

ABSTRACT

The principle of this method was already presented at the Second Symposium on N D T of tyres (Atlanta – Ga – october 1974).

Since then a prototype of a industrial machine has been designed and manufactured.

With this machine systematic series of test on various tyres of different sizes, different retreading ranks, and in use in different Air Transport Companies has been carried on.

The paper presents a short review of the method, the characteristics of the equipment and results of the test program with emphasis on the statistical analysis of these results in correlation with the life-time of the tyres.

I – INTRODUCTION

Tire failures are still a nuisance in airline operations. Such failures may cause delays, cancellations, structural repairs and in some instances even flight safety may be impaired to various degrees.

That is the reason why many efforts are currently made in order to develop valuable non destructive methods of tire quality evaluation.

One well established method is the airneedle test. Air is injected under pressure into the cords of the carcass by means of a needle prior to retreading. The injected air diffuses along the carcass plies building up an internal pressure. Areas of ply separations from the rubber are shown as local bulges which can be detected by the operator visually and/or by feeling with his hands. These defects occur mainly in the areas shown in Fig. 1. This method is simple to be performed but it has low sensitivity and depends greatly on the operator himself.

The radioactive tracer method [1] (PNEUTEST), which was already presented when the experiments started at the Second Symposium on NDT of tires [2] is a development of this method.

In place of the regular shop air, the injected medium is a mixture of nitrogen and a radioactive gas, xenon 133.

A prototype of an industrial NDT equipment based on this method has been designed and manufactured. With this equipment systematic tests are carried on with the cooperation of AIR-FRANCE, KLEBER and with the financial support of the French Civil Aviation Board (DGAC).

Before describing the equipments and the results, we shall give a brief description of the principle of the method.

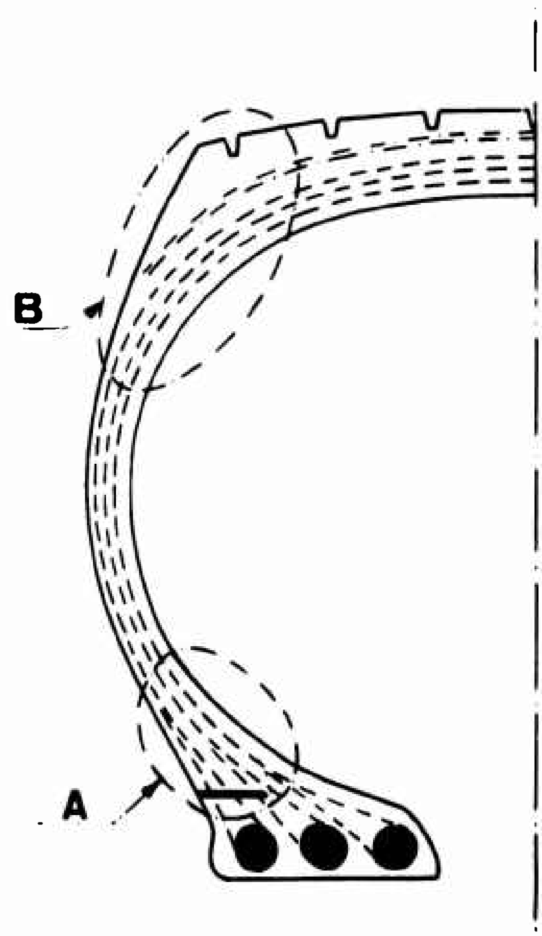

FIGURE 1
TYPICAL SHAPE OF A TUBELESS AIRCRAFT TIRE
(A & B are the areas of maximum fatigue)

II – PRINCIPLE OF THE PNEUTEST METHOD.

II – 1 Injection.

One uses a mixture of nitrogen and xenon 133 (which emits soft γ rays (81 keV) and has a half life of 5.27 days) at a constant pressure of 8 bars (125 PSI).

This radioactive gas is injected with two needles in the vent holes area of the tires (Fig. 2). The injection time varies between 3 to 10 minutes depending on the size and the wear of the tire to be controlled.

II – 2 – Increase of count-rates on points diametrically opposite to the injection points, during the injection.

During the injection one records the count rates of two probes (scintillation probes) which are applied to the tire on points diametrically opposite to the injection points.

As the gas diffuses along the cords of the carcass plies, the count rates increase. This gives a measurement of the diffusion rate of the gas inside the structure of the tire. For new tires this rate is equal to zero and one can observe actually no significant increase of the count rates.

Higher will be the global fatigue of the tire, greater will be the diffusion rate, i. e. the increase of the count-rates.

It seems to us that this method which is rather simple to be operated will be able to detect fatigue of tires at an early stage before any occuring of local defects like blisters.

II – 3 – Scanning of the count rate around the tires.

After the injection and the first control done during it, the needles are disconnected from the tire.

With four probes pressed against the tire, set in a fixed position, in the four areas of maximum fatigue (shoulders

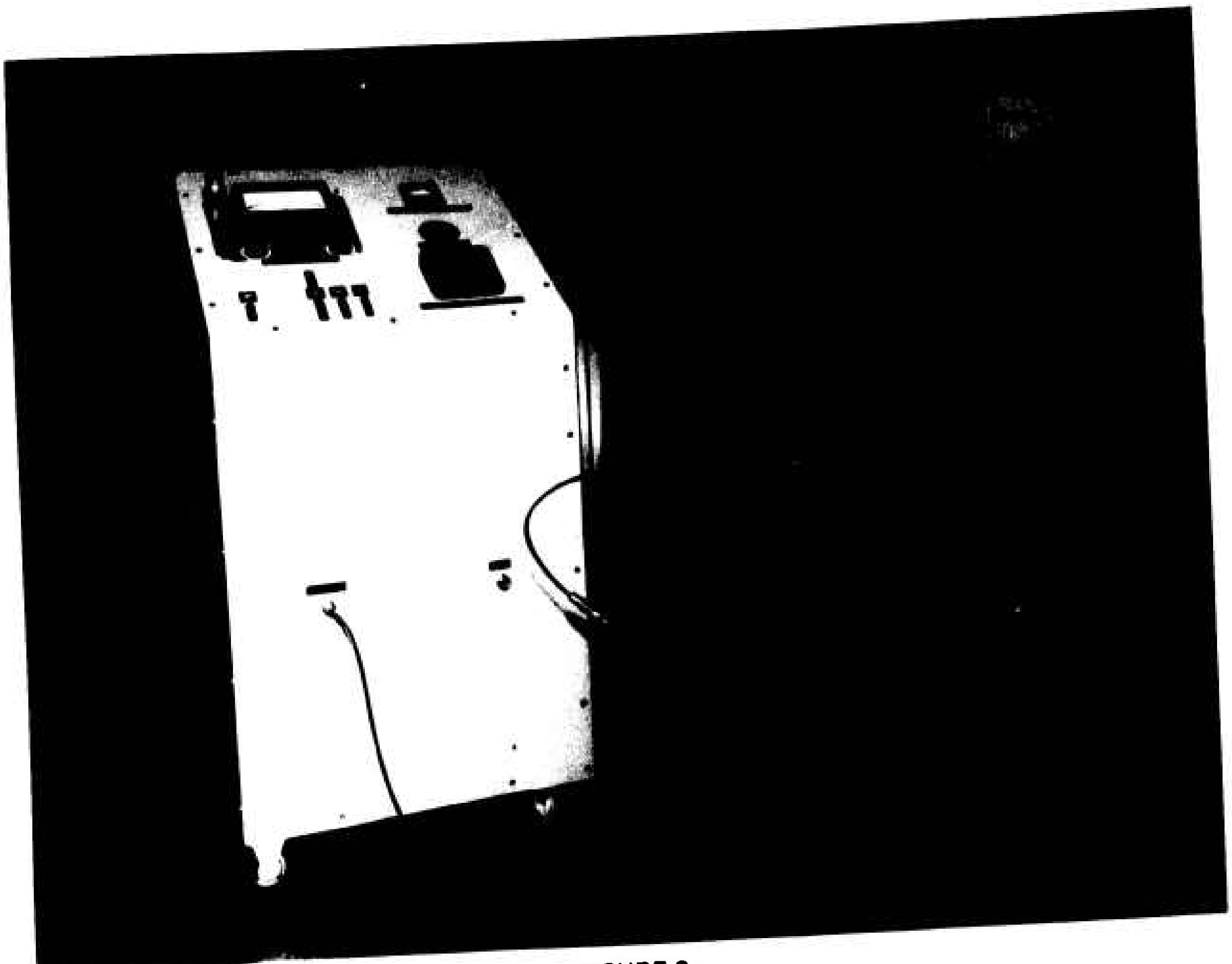

FIGURE 2
INJECTION DEVICE
(the tire shown is a 52 x 20.5)

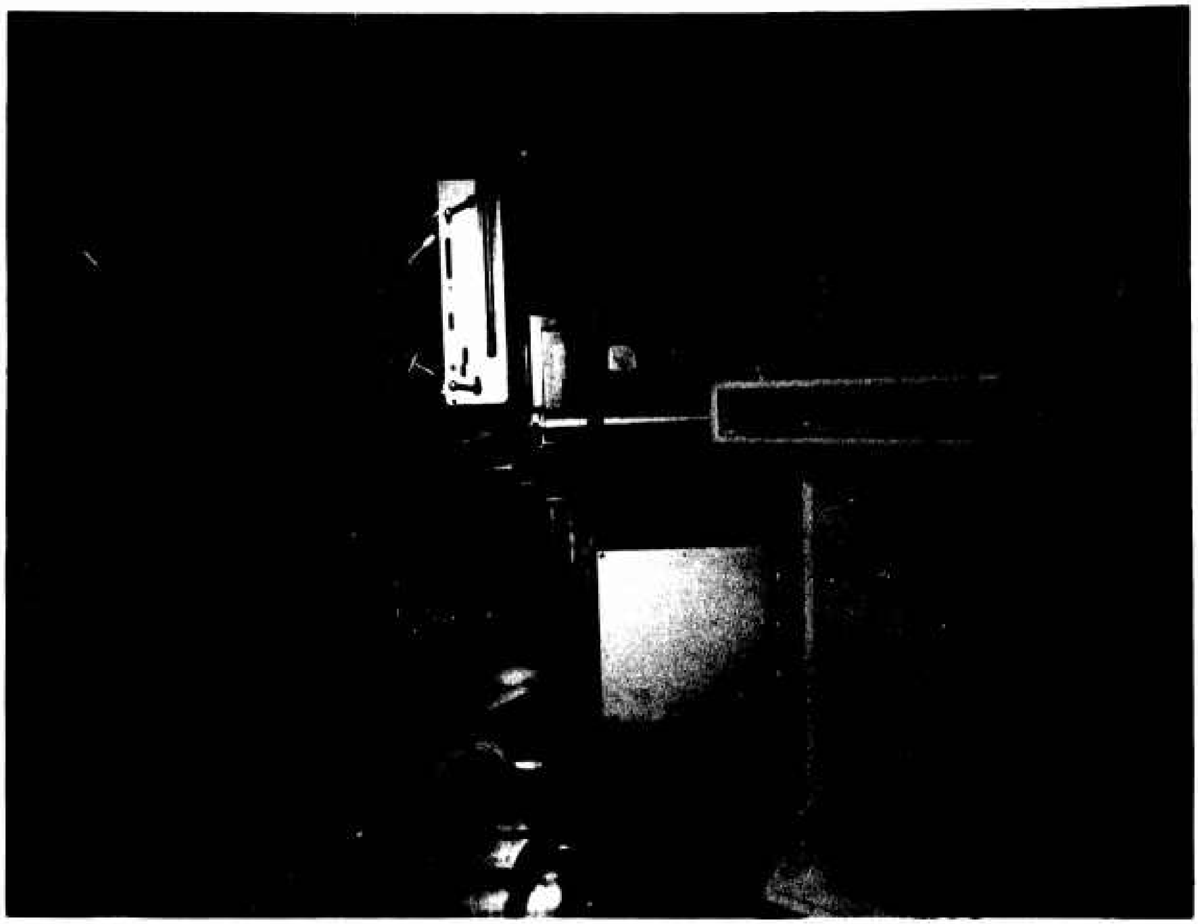

FIGURE 3
EXPLORATION MACHINE – STAND-BY POSITION
(the tire shown is a 52 x 20.5)

and beads areas), one makes a scanning of the distributed activity, by rotating the tire around its axis.

So in polar coordinates the activity is maximum just at the injection point, and normally minimum a 180° from it.

Using this mode of graphical display of the results, one observes that for a tire which is little used and which presents no local defect the repartition curve of the activity looks like curve I (Fig. 5). The ratio between the count-rate at 180° from the injection point (R_{MIN}) and the one over the injection point (R_{MAX}) could represent the global wear of the tire.

$$\text{So } T_G = \frac{R_{MIN}}{R_{MAX}} = 0 \text{ for a new tire}$$

and

$$T_G = \frac{R_{MIN}}{R_{MAX}} \text{ has a tendency to approach 1 for a tire "completely" worn}$$

Thus the curve II is a characteristic of a tire more worn than the tire of curve I.

The curve III is a curve of a tire which has the same global porosity (or fatigue) index T_G as the one of the curve II, but it presents 2 local defects.

III – CHARACTERISTICS OF THE PROTOTYPE EQUIPMENT

III – 1 – Injection device.

It is an electro-pneumatical device (Fig. 2). It needs a regular industrial nitrogen bottle. The pressure is set to about 8 bars (125 PSI). One uses xenon 133 scaled ampules. The mean tracer consumption is less than 0.5 mCi per tire.

For a daily maximum control frequency of 100 tires (in 2 x 8 h), this requires 50 mCi.

The time of injection varies between 3 and 10 mn and can be preset. All the valves are electrically driven and backwards locked. The activity per volume of mixture is continuously measured with an ionization chamber and galvanometric display.

One uses two scintillation probes equipped with thin Na I (T1) crystals of 1½" diameter, two integrators and a 2 channel linear recorder.

III – 2 – Exploration devices.

The prototype machine is designed to control automatically tires of various sizes (32 x 11.5 – 15 and 35 x 9.00 – 17 up to 52 x 20.5 – 23 in fact 15 to 23 inches rim ledge diameters).

It is an electro-pneumatic device which requires pressured air (6 bars or 90 PSI).

The tire is rolled on the platform (A). Six different sizes of tires can be preset. Then the rails (B) clench the tire. The platform climbs up to set the axis of the tire up to the level of the shaft (C). This one moves forward in the center of the tires. The jaws (D) expand. (Fig. 3).

The rails set the tire free. The four probes are pressed against the sidewalls of the tire. Then the shaft rotates (one revolution in about 5 mn). The four scans are recorded. (Fig. 4).

Then all the mechanical sequences are reversely done. The complete sequence takes about 7 mn.

IV – EXPERIMENTS BEING CARRIED ON.

On various tires of nose wheels or main wheels of various civil transport aircrafts, experiments have been carried on with this equipment for about one year.

The main goals of this work are:

(1) determine the various parameters to be taken in account and optimize them,

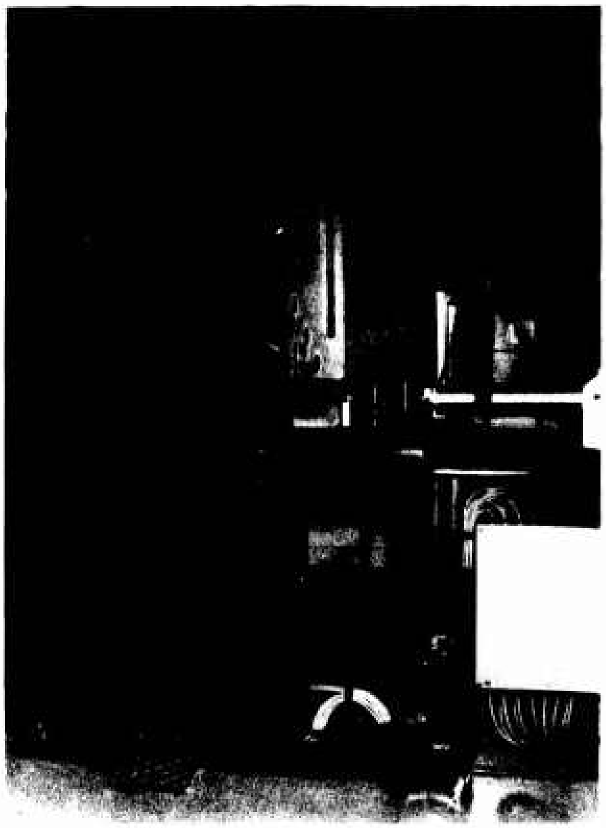

FIGURE 4
EXPLORATION MACHINE, DURING THE SCAN
(the tire shown is a 52 x 20.5)

(2) make correlation between the rate of diffusion of the tracer gas during the injection and the fatigue of the tire, than means with the number of takings off and touches down. The Figure 6 shows an example of correlation between such values. The tires are 49 x 17/30 PR – 225 MPH from the same manufacturer used on Boeing B 747 SP main wheels of the same company (R02).

(3) make correlation between this rate of diffusion and the excentration of the scans T_G. The figure 7 shows an example of correlation between such values. The tires are 46 x 16/24 PR-210 MPH from the same manufacturer used on Airbus B 2 main wheels of the same company (R00 and R02).

(4) make correlation between eventual local defects shown by the scans and destructive tests in order to be able to predict the type of defect to be detected.

For this reason a lot of 46 x 16/30 PR used on BOEING 747 main gears of the same company were identified and are currently being put in service. Before each retreading all the tires have been controlled in the same manner.

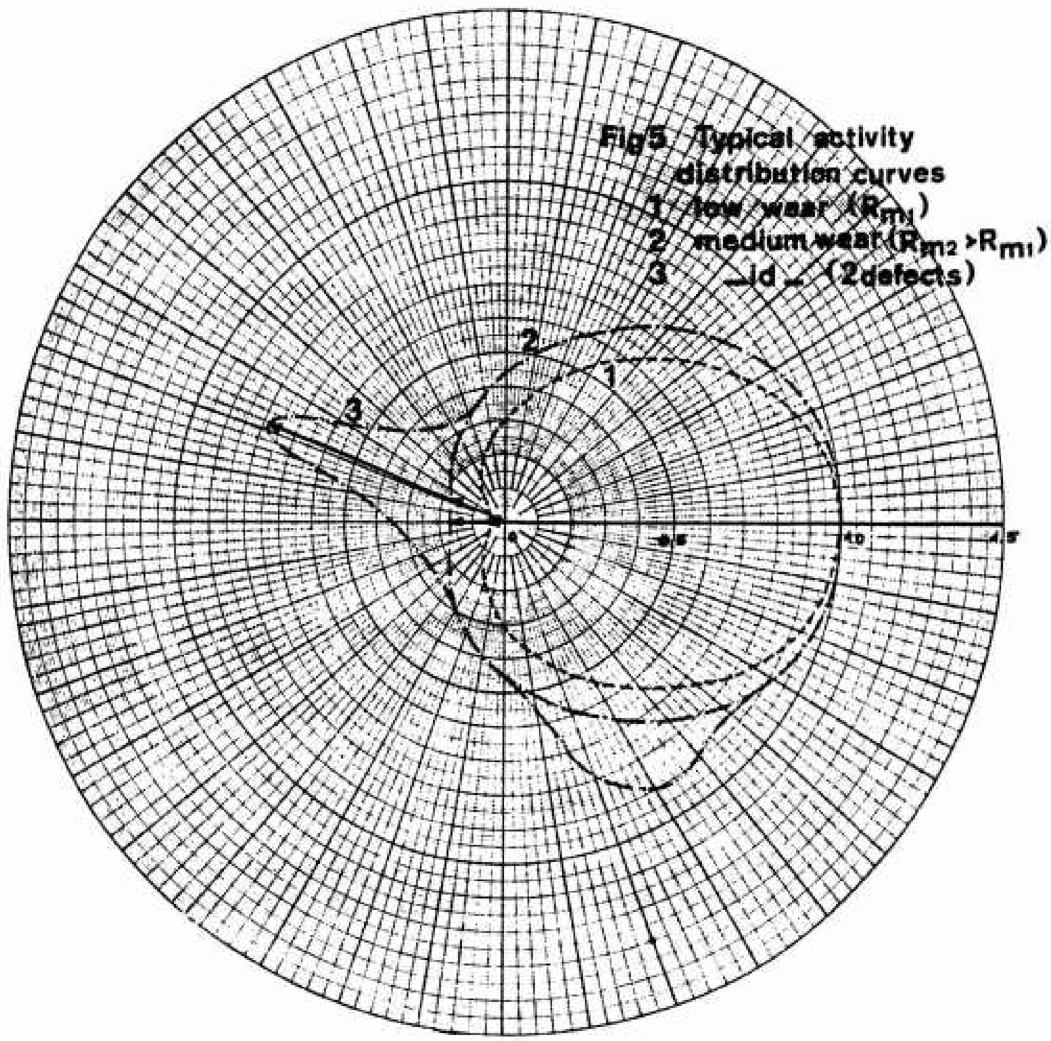

FIGURE 5

All the data are stored on magnetic files in order to check and to study their evolution in connection with the lives of the tire. At each retreading a certain fraction of the lot will be cut to get destructive examination information.

This will be done till all the tires of this population will be withdrawn from duty.

Moreover another series of tires (same manufacturer – same size) have currently been subjected to endurance tests. There are controlled after 200 - 400 - 600 . . . . km rolling tests in the same manner, in order to get quantative equivalence to the data obtained on tires used in airline service.

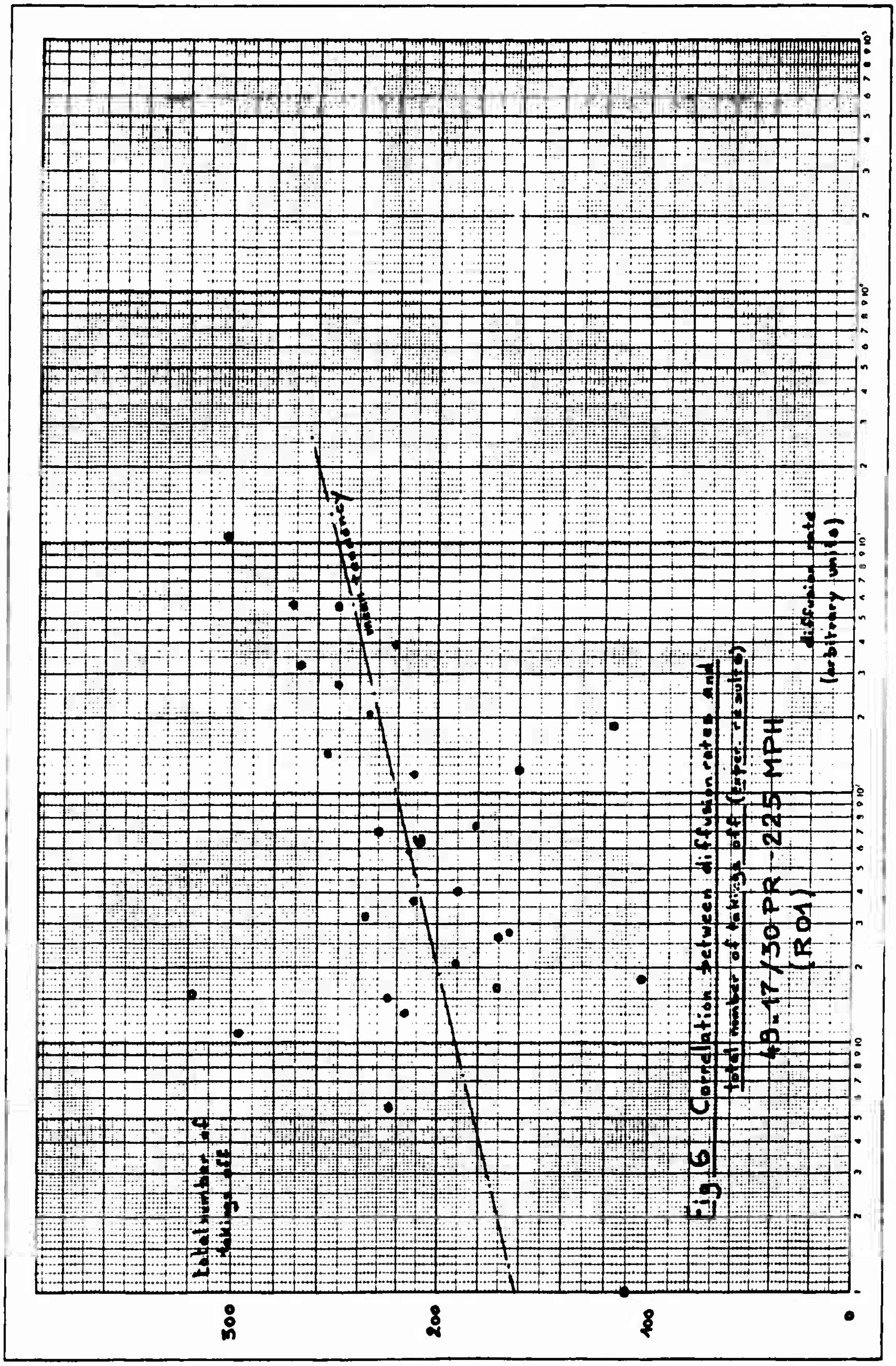
Fig. 6 Correlation between diffusion rates and
total number of takings off (exper. results)
4B-17/30 PR - 225 MPH
(RD1)
total number of takings off
diffusion rate
(arbitrary units)
mean tendency
300
200
100
0

FIGURE 6

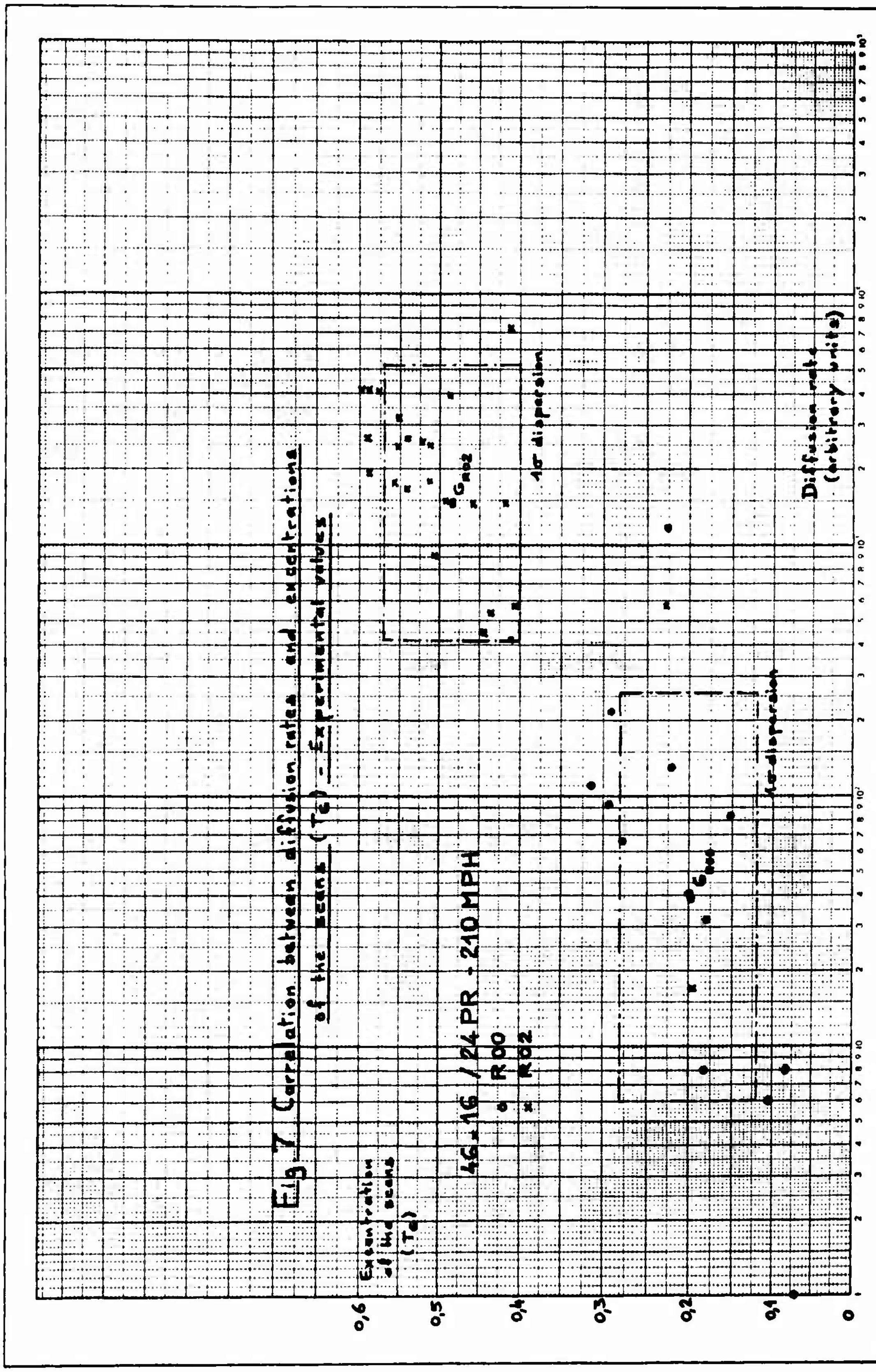

Fig 7 Correlation between diffusion rates and excentrations of the scans (Te) - Experimental values
46x16 / 24 PR - 210 MPH
o R00
x R02
Excentration of the scans (Te)
Diffusion rate (arbitrary units)
1σ dispersion
1σ dispersion
0,6
0,5
0,4
0,3
0,2
0,1
0

FIGURE 7

V – CONCLUSIONS

The experimental machine has now been in operation for about one year. All the procedure and safety and regulation problems have been carefully solved.

We think that within one year the systematic tests on airline service tires will give us qualitative and quantitative results that will ensure us about the true capability of this method and the associated equipment to help airline companies, tire manufacturers and retreaders to increase the cost/safety balance of aircraft tires exploitation.

We wish to thank the friendly assistance of our colleagues from AIR-FRANCE and KLEBER during all this week and especially M. LAFANECHERE from KLEBER.

Our thanks also go to Mr. Paul E. J. VOGEL for his invitation to this Symposium and for his help to introduce this paper.

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A SECOND GENERATION HOLOGRAPHIC TIRE TESTING UNIT

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Description of the HRT 56

1. Based on many years of experience, not only of holographic tire testing but in many other industrial applications of holography, we have developed a tire testing unit which incorporates the most modern technologies in this field.

The advantages of holographic test methods are already very well known and during the course of this meeting the capabilities of holographic tire testing have already been discussed. Therefore, this paper concentrates on the description of a particular unit with which practical holographic techniques may be applied.

The HRT 56 holographic tire testing unit is exceptional because it incorporates the following special features:

1. The testing process is completely automatic and uses an instant photo-thermoplastic film which is manufactured by the firm of Kalle-Hoechst. Further, the test results are instantly available. The old fashioned methods using silver halide film materials are not only messy and complicated, but also a delay time of test results of up to one hour is involved.

2. Our specially developed optical arrangements makes possible the use of a single hologram per tire. Old fashioned methods using four holograms per tire cost not only time but also money.

3. Bead inspection, so important for truck and aircraft tires, can also be carried out on our specially constructed unit.

The unit is, of course, designed for the severest production environmental conditions and is fully isolated from ambient influences such as dust, vibration etc.

Our holographic tire testing unit is, as a result of the incorporation of the most modern technology and a test capacity of 1000 tires per day, the best test unit of its kind available today.

The holo tire testing unit HRT 56 is suitable for non-destructive testing of tires of all types up to an outside diameter of 56". Individual faults and structural characteristics can be inspected. The unit is the result of many years of development and it is based on the principle of holographic interferometry. The robust construction of the HRT 56 allows a high degree of sensitivity even under noisy operating conditions. Therefore, the unit is suitable for installation on the production floor as well as in the laboratory.

Many tire investigations have shown that holographic tire testing is capable of delivering clear information with respect to:

- tire construction
- quality control
- tire life expectancy.

This guarantees a broad applications field covering virtually the whole tire production spectrum.

2. Principle

The principle of holographic tire testing is based on the fact that faults in the tire produce minute alterations of the surface contour of the inner face when the ambient pressure is slightly changed. Pressure reductions of a few hundredths of an atmosphere lead to contour changes of something less than one thousandth of a millimetre. These minute contour changes can be registered using the holographic technique. Fig. 1 shows the schematic arrangement of the HRT 56 tire testing unit.

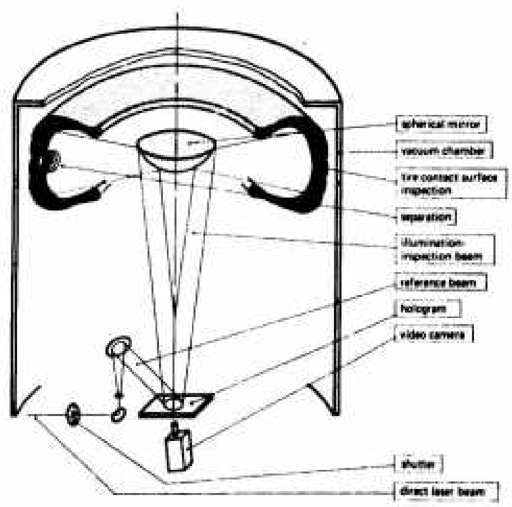


FIGURE 1
Schematic arrangement of the HRT 56 tire testing unit.

The holo tire testing method employs a laser to illuminate the inside of the tire. The light reflected from the tire surface goes directly to a photo-sensitive material, without passing through any lenses. By superimposing the laser light returning from the tire with a direct laser beam on the photo-sensitive material (reference beam), the light wave pattern is recorded directly onto the photo-sensitive material. The photo-sensitive material on which the wave pattern is recorded is described as a hologram. Using a particular optical set-up, it is not necessary to divide the tire into portions and make a separate hologram for each portion. A single hologram contains the complete tire information. With the holo tire testing method, the photo-sensitive material is exposed twice. The first exposure is made under normal pressure conditions and the second is made after applying a slight vacuum. The hologram is made on a photo-thermoplastic material which obviates the use of chemicals for development and reduces the whole process to a few seconds. After the short processing time, the wave patterns which have been stored in the hologram are reconstructed by illuminating the hologram with the so-called reference beam. Looking through the hologram (see fig. 2) one can see an interference fringe pattern on the inside of the tire. This pattern shows the contour changes on the inside of the tire to an accuracy of approximately one half of one thousandth of millimetre. The image is viewed at a TV-monitor.

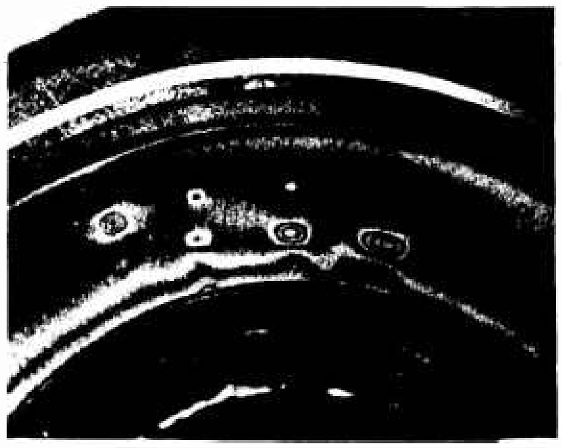


FIGURE 2
Monitor image of a specially prepared tire

The holographic testing method has first been made practical with the introduction of the HRT 56. The use of holography in a production environment was impractical because a wet processing was required with old fashioned photographic materials. This barred the use of holography in production and the first generation test units were used only in the development field for over ten years. The wet processing was not able to be automated. The holo tire testing unit HRT 56, with its use of a new photo-thermoplastic material has broken through this barrier.

Many new developments in the HRT 56 make it the most advanced unit of its kind at the present time. Some of its particular advantages are the following:

1. extremely short cycle time,
2. completely automatic operation,
3. instant test results,
4. one single hologram for the complete tire,
5. bead inspection without optical adjustment.

3. Image diagnosis

The test results are presented in the form of a TV image. This form of presentation has the advantage of rapid location and quantitative analysis of tire faults. Subjective errors are eliminated. This diagnosis of the monitor image can be applied to virtually all fields of tire manufacture. One of the most important data is concerned with the life expectancy of the tire. The life expectancy, and therewith also the quality of the tire, is influenced considerably by individual faults and by structural weakness in the tire carcass. Both of these effects can be inspected on the TV-monitor.

The tire constructor can establish the tendency to such weaknesses during the construction and testing phase, using the holographic diagnosis technique. Faults can also occur during production due to human error. Faulty material or faulty storage of the tire can lead to a premature fatigue of the tire structure. Holographic testing allows the detection and correction of such faults.

In the field of tire retreading, the life expectance is of major importance. Using holographic testing techniques, faults which have occurred in the past life of the tire may be determined and then decided whether the tire should be retread. Therefore, without any sacrifice of safety factor, a much more economical usage of tire carcasses can be achieved. Other safety factors, such as a larger minimum profile depth, can be taken into account witthout financial burden on the tire user.

The monitor image contains all the necessary information for diagnosis. Individual faults are seen as ring patterns (see fig. 2 and 3) with an elliptical form. The geometrical dimensions of the separation are determined with the help of a mask. Frequently, there are cases of several closely grouped individual faults. These faults, which are typical for belt edge or shoulder area, indicate an extremely dangerous situation as when such individual faults flow together, they drastically shorten the life expectancy of the tire. The monitor image presents

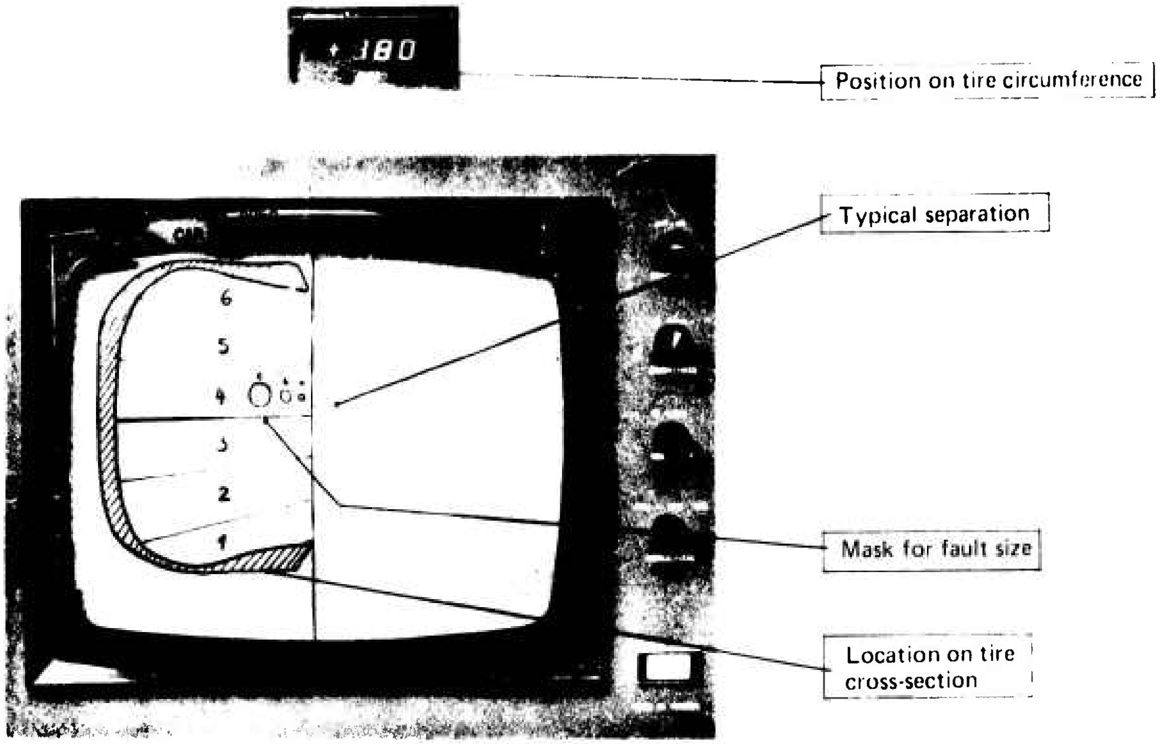


FIGURE 3
Establishing the size and location of a tire fault

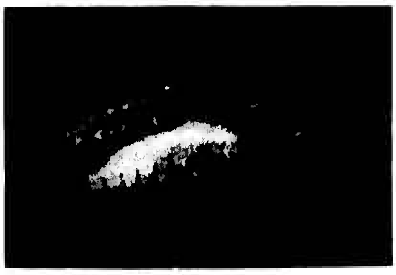


FIGURE 4
Chain separations in crown centre

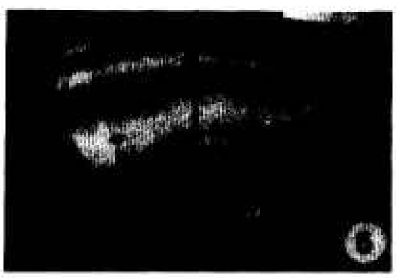


FIGURE 5
Background fringes provide information about carcass structures.

the possibility to ascertain the likelihood of a flowing together of several closely grouped individual faults. With the use of the mask, the location of the fault can be exactly determined on the tire cross-section (e.g. shoulder area). The depth of the fault can be determined by the number of rings, checked against a master tire. The fault position on the tire meridian is indicated on a digital counter. The carcass structure condition can be inspected by means of the background fringe patterns which run tire circumferentially. The uniformity is indicated by the more, or less central position of the rings. The density and structure of the fringes give an indication of the porosity or degree of fatigue of the tire.

The information which is read out on the TV monitor is transferred to a printed form – an example of which is shown in fig. 6.

The coordination of all the parameters obtained from the image diagnosis allows the assessment of the condition, and therewith also the life expectancy, of a tire. These parameters are:

- fault size (circumferential)
- location of individual faults on meridian (e.g. crown, shoulder, bead)
- several closely grouped separations
- condition of carcass

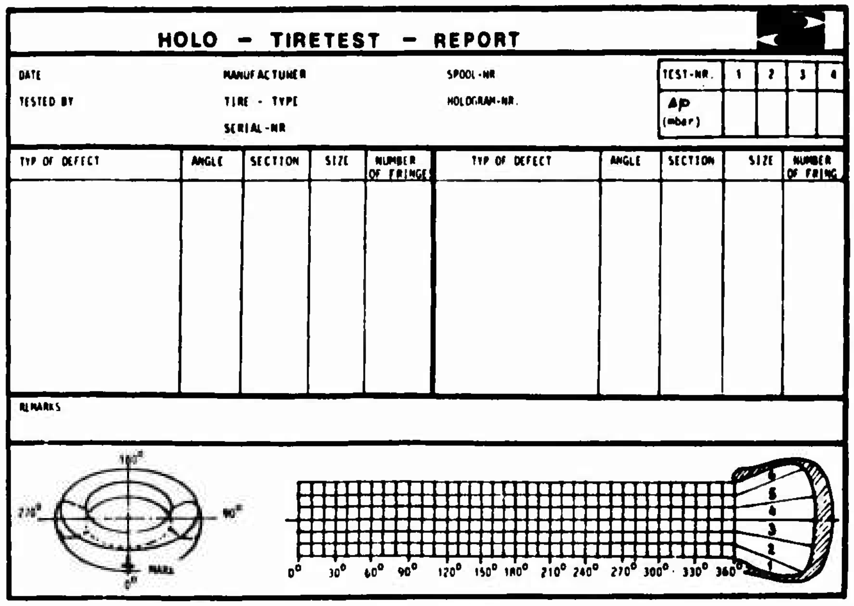


FIGURE 6
Example of Holo tire test printed form

The influence of these parameters on the life expectancy of a particular tire is dependent on the various types of tire construction and must be ascertained for each individual type, whereby specific quality criteria are established in conjunction with the tire manufacturer or retreader.

4. System description

The testing process involves three steps:

- tire manipulation
- automatic test unit functions
- evaluation of the test results on the TV monitor (as described in "Image diagnosis").

The individual function steps can be seen in the following time graph (fig. 8). Time graph I shows the function steps with a one operation, typical for development and limited series applications. Time graph II is for a two man operation in a production environment. With an approx. 80% efficiency in a three shift operation, a figure of 1000 tires per day/tested can be achieved.

4.1 Tire manipulation

Tire manipulation means: on and off-loading of the test unit. For heavy truck and aircraft tires a crane is used. The tire is then placed in a pan, which is apart from the test unit, and is rolled into the unit on a railed platform (shown in fig. 9). The tire is not on a rim. A certain length of time, dependant upon the type of tire under test, is required for the tire to "settle". For car tires, a settling time or relaxing time of approximately five minutes is sufficient, where aircraft tires only require as little as one minute as a result of their more stable structural characteristics. The influence of the relaxing time on the actual testing time can be obviated in a simple way by having several tire stations. The relaxing stations, which are also used as the loading stations, are constructed on the "building block" principle and can, therefore, be tailored exactly to requirements. A number of different steps are required (depending upon tire type and test-cycle time) when testing tires. If, for instance, a tire life history is being compiled, the serial number and exact fault positioning is most important. This is generally necessary in development applications and retreading quality control. Tires with very dark surface may be sprayed with talcum powder to improve their reflectance. Depending upon tire type and the required tire test area, the tire may be spread open with metal spreading posts. The spreading, however, does lead to a certain lengthening of the relaxing time, and is therefore to be done some time prior to the actual test period.

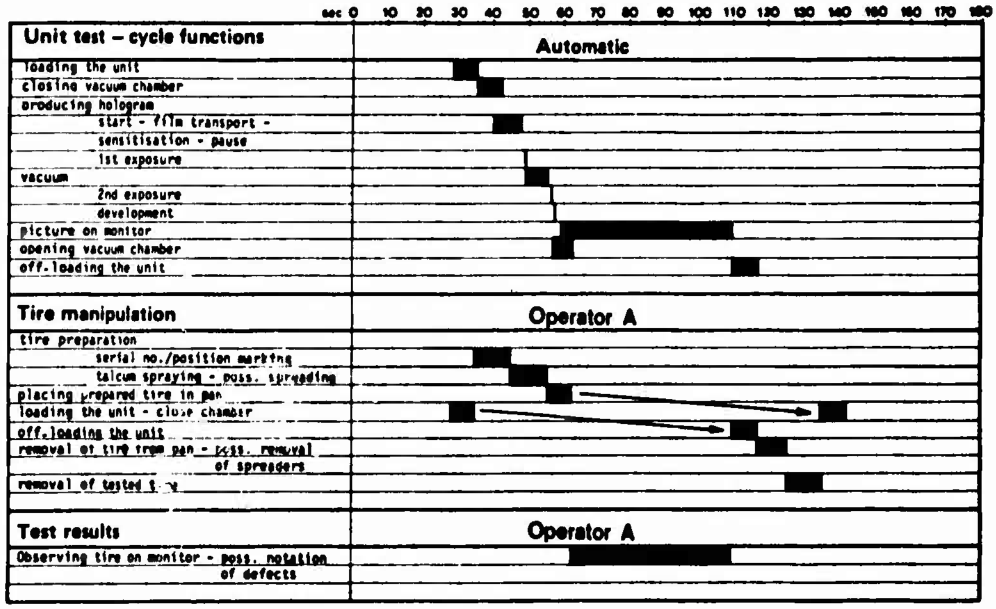
4.2 Test unit

After the tire pan, with the tire, is rolled into the test unit (see fig. 9) the actual testing process begins with the closing of the vacuum chamber bell. (Details may be seen in the time graphs). A vacuum of 0 to 250 mbar can be achieved in the vacuum chamber, and is regulated by a manometer. A so-called double exposure hologram, is made of the tire. The hologram is made on a photo thermoplastic film material which bears the name "PT Instant Film".

The PT instant film was developed by the firm of Kalle-Hoechst AG and Rottenkolber Holo-System has an exclusive licence on this film. The processing is non-chemical and takes only a few seconds. High sensitivity (5 erg/cm^2), high resolution (1000 lines/mm) and a high diffraction efficiency (max. 30% assure good

TIME GRAPH I

total testing time : 120 sec
operator : 1



TIME GRAPH II

total testing time : 1 min
operators : 2

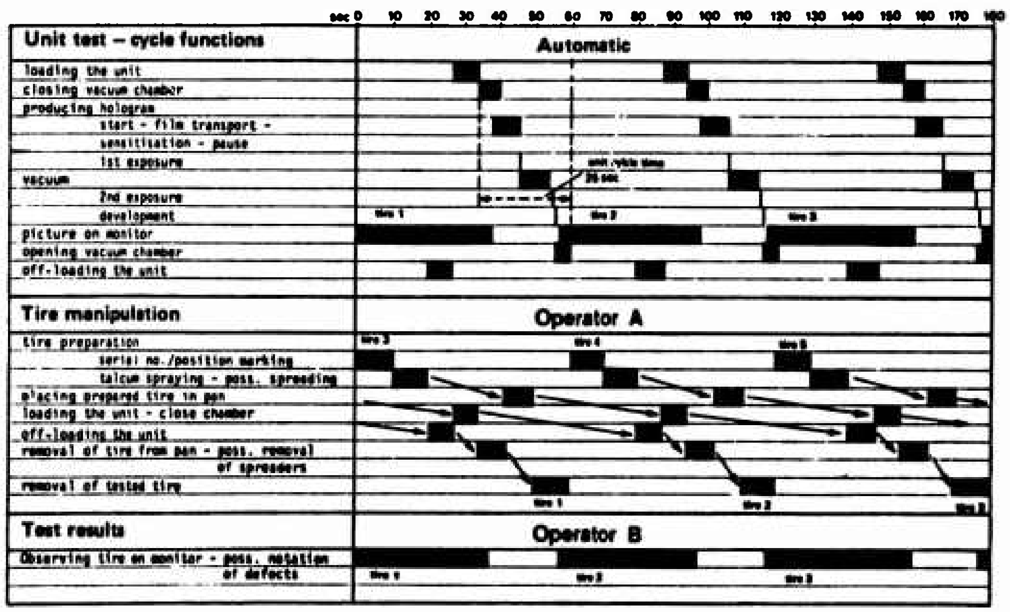


FIGURE 8
Time graphs

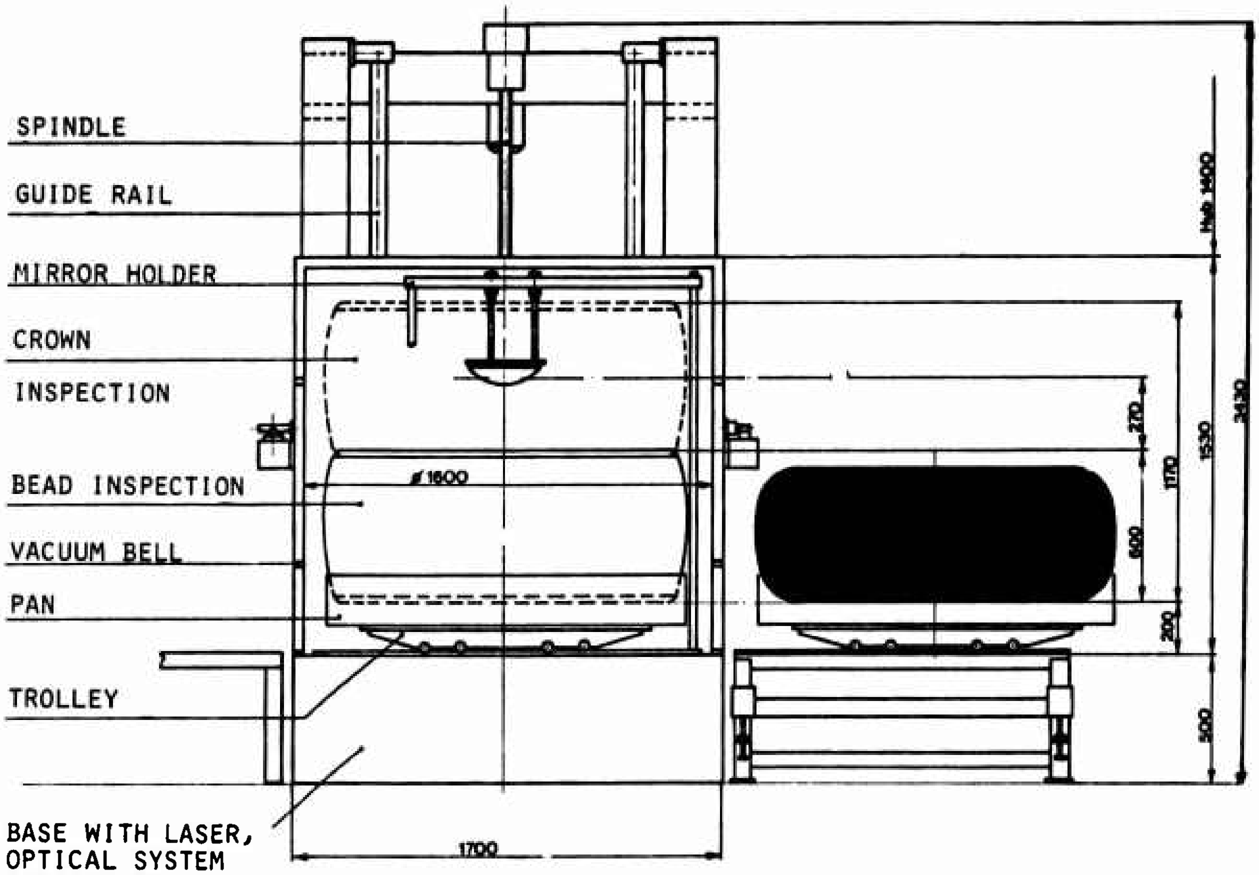


FIGURE 9
General arrangement of the Holo tire test unit HRT 56

quality holograms with a short exposure time and a relatively low light output. The 35 mm film is delivered on spools containing 30 m film length (sufficient for 1000 holograms). The holograms are storable for many years and they can be reconstructed in an external appliance or in the test unit itself. A hologram counter makes the location of particular holograms a simple matter. Therewith, a tire life can be followed through all of its stages and can be compared with previous stages, as required. This is of particular importance when dealing with the study of fault or fatigue problems.

The complete tire circumference can be viewed by a spherical mirror, and therefore, only one single hologram is necessary per tire. The tire image is reconstructed from the double exposure hologram and is inspected by a TV monitor feature. Optical enlargement ensures a high degree of fault resolution. The complete tire is inspected by rotating the TV camera, whereby, the tire position is indicated on a digital counter. Using this counter, an exact location of the fault on the tire circumference can be read. Using the mask, the fault can be located on the cross section of the tire and its geometrical form and size can be established. A subjective faulty diagnosis is largely cancelled out using this method. The test results appear on the TV screen two seconds after exposure.

The holo tire testing unit HRT 56 is equipped with a highly efficient vibration damping system which assures a good quality of holograms even in a production environment. The optics system is sealed off and is thereby kept free of dust. The whole process from loading the unit to viewing the test results on the TV screen is automated. Without the need of readjustment of the optics, all tire sizes can be inspected by means of a simple mechanical adjustment of the tire pan.

5. Testing the bead area

As a second generation system, the HRT 56 makes possible the inspection of the bead area. The inspection of the bead area is of particular importance when dealing with truck and aircraft tires because a large number of the failures which occur in this field of applications, occur in the bead area. For this type of inspection, the only adjustment necessary is the height of the tire pan relative to the spherical mirror. No optical adjustment is required. The fault location, establishing of fault size as well as the cycle time is comparable with that of the crown test cycle. Regardless of tire type, there are three different methods of tire inspection as seen in Figures 10, 11, and 12.

FIGURE 10

"Bead-crown-bead". – This method is always possible when the tire may be spread apart. It is only used for car tires of special construction. In this case, the tire may be tested in one single test cycle.

FIGURE 11

"Half-crown-bead". – This method may be used when the tire can be spread apart only a little. Most car and truck tires are under this heading. In this case, two test cycles are necessary.

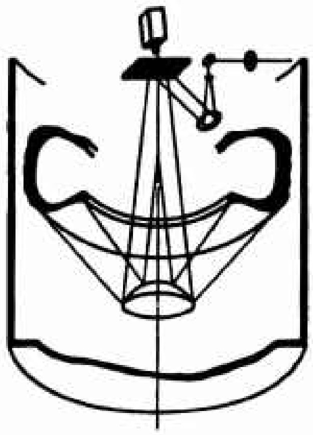


FIGURE 12

"Bead from outside tire". – This method is used when the tire can hardly be spread apart at all, which is in case of most aircraft tires. In this case, three test cycles are necessary.

6. Conclusion

The holo tire testing unit HRT 56 as described here is exceptional in its automatic test cycle. This is made possible by employing the most modern technology. It offers all the prerequisites for "one line" production testing.

Lastly, a look at the cost factors:

Test costs balance of a single tire break down as:

- 40% unit depreciation
- 30 % running cost
- 30% personnel cost

The absolute test costs are dependent on the tire type and test capacity factors. As a guide, one may assume approximately one dollar. I feel sure that the relatively modest test costs are justified by the great increase in tire safety which can be achieved using holographic test methods.

PRODUCTION X-RAY, 1978

T. Neuhaus
Monsanto Company
Akron, Ohio

This paper reviewed recent advances and design changes in production x-ray systems. Modifications have been the result of increased inspection and output demands by the tire industry.

Systems to be discussed were:

1. Computerized Automatic High Production Passenger and Truck Tire Systems.
2. Air Inflated, Automatic Passenger and Light Truck Tire Systems.

SOME NEW TRENDS AND DIRECTIONS IN THE WORLD OF SPECIFICATIONS AND STANDARDS

R. Chait
Army Materials and Mechanics Research Center
Watertown, Massachusetts

As most of you know, standardization documents that are part of the Defense Standardization Program (DSP) are used in the procurement of many DoD items including tires. What I will discuss with you this morning are some of the new trends and directions in the world of specifications and standards as viewed from a DSP perspective. In particular, there have been several studies in recent years that have concerned the DSP that you should be aware of. I will examine these studies and point out some of the recommendations that have been forthcoming. Also, I will describe the DoD followup to these recommendations in terms of new initiatives that have been seen. Lastly, I will comment on just a few of the DSP specifications and standards that deal with tires keeping in mind these initiatives.

To begin, let me show (vu-graph 1) some of the more important studies/hearings that have concerned themselves with our country's standardization efforts. After World War II, Congress became very interested in how the Government was procuring the various items it used during the war effort. To reduce the proliferation of items among the armed services, Congress passed the Cataloguing and Standardization Act in the early 1950s. DoD's answer to this legislation was the DSP which provided for control of item proliferation by a) preventing the preparation of duplicative and overlapping descriptions of materiel, b) fostering reuse of existing technology to satisfy new system requirements, c) developing methods for reviewing items in the inventory to reduce or eliminate varieties and sizes, and d) establishing as appropriate, uniform type grades, classes and sizes of items and levels of performance requirements which define physical properties of materiel.

By and large, this program has been successful and has been used as a model for foreign countries to emulate. There are some 46,000 documents in the DSP. These are listed in the Department of Defense Index of Specifications and Standards or what is commonly referred to as the DODISS. To review, each military specification is uniform in its format and contains different sections devoted to the scope of the specification, what other standardization documents are applicable, important requirements, quality assurance provisions to insure requirements are met, delivery aspects and miscellaneous notes. To complete the review, let us examine the first page of a typical document (vu-graph 2). This specification is MIL-A-12650C(MR), Armor Steel Plate, Wrought, Homogeneous; Combat-Vehicle Type (¼ to 6 inches, INCL.), as is shown in the top right-hand corner. "MR" is the abbreviation for the installation charged with the preparation of the document. In this case, it is the Army Materials and Mechanics Research Center (AMMRC). "A" is the first letter in the first word in the title. In the bottom right corner is the identification FSC 9515. As we will see in a moment, all documents that are a part of the

STUDIES/HEARINGS

- HOUSE ARMED SERVICES COMMITTEE 1952
- HOUSE COMMITTEE ON GOVERNMENT OPERATIONS (HOLIFIELD REPORT) 1971
- REPORT ON TASK FORCE ON SPECIFICATIONS AND STANDARDS 1977
- NMAB REPORT ON MATERIALS AND PROCESS SPECIFICATIONS AND STANDARDS (NMAB 330) 1977
- NMAB REPORT ON ECONOMIC AND MANAGEMENT ASPECTS OF NONDESTRUCTIVE TESTING, EVALUATION AND INSPECTION IN AEROSPACE MANUFACTURING (NMAB 337) 1977
- PRESIDENTIAL POLICY ON NATO STANDARDIZATION 1975-1977

VU-GRAPH 1

MIL-A-12560C(MR)
9 July 1976
SUPERSEDING
MIL-S-12560B(ORD)
31 July 1962

MILITARY SPECIFICATION

ARMOR, STEEL PLATE, WROUGHT, HONOGENEOUS; COMBAT-VEHICLE TYPE (1/4 to 6 INCHES, INCL.)

This specification is approved for use by the Army Materials and Mechanics Research Center, Department of the Army, and is available for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers wrought-steel combat-vehicle type of homogeneous armor plate in thicknesses from 1/4 to 6 inches inclusive (see 6.1 and 6.4).

1.2 Classification. Wrought armor shall be of the following classes as specified.

1.2.1 Class 1. Wrought armor plate which is heat treated to develop maximum resistance to penetration.

1.2.2 Class 2. Wrought armor plate which is heat treated to develop maximum resistance to shock.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

STANDARDS

FEDERAL
Fed. Test Method Std. No. 151 – Metals; Test Methods

MILITARY
MIL-STD-129 – Marking for Shipment and Storage

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

/FSC 9515/

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Army Materials and Mechanics Research Center, Watertown, MA 02172 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

VU-GRAPH 2

DSP are identified with a particular class or area as detailed in the Defense Standardization Program Direction, the SD-1. For example, our standardization responsibilities at AMMRC are varied and cover the classes shown on the next (vu-graph 3).

I would like to return to vu-graph 1 that lists the studies and hearings that have concerned themselves with standardization activities. In 1971, Congressman Hollifield chaired an important House committee which recommended that the responsibility for policy and coordination be assigned to a central point-of-authority which within DoD now rests with the Director, Defense Research and Engineering. In addition, it was stated that this coordination should integrate both development and logistics. For this purpose, the Defense Materials Specifications and Standards Board was established.

AMMRC

STANDARDIZATION MANAGEMENT RESPONSIBILITY

FSC	TITLE
FORG	METAL FORGINGS
MECA	METAL CASTINGS
MFFP	METAL FINISHES & FINISHING PROCESSES & PROCEDURES
MISC	MISCELLANEOUS
NDTI	NONDESTRUCTIVE TESTING & INSPECTION
THJM	THERMAL JOINING OF METALS
3439	MISC. WELDING, SOLDERING & BRAZING SUPPLIES & ACCESSORIES
4710	PIPE AND TUBE
5330	PACKING & GASKET MATERIALS
5345	DISCS & STONES, ABRASIVE
5350	ABRASIVE MATERIALS
6850	MISC. CHEMICAL SPECIALTIES
8010	PAINTS, DOPES & VARNISHES
8030	PRESERVATIVE & SEALING COMPOUNDS
8040	ADHESIVES
8470	ARMOR
91GP	FUELS, LUBRICANTS, OILS & WAXES
9130	LIQUID PROPELLANTS & FUELS (PETRO BASE)
9140	FUEL OILS
9150	OILS & GREASES (CUTTING, LUBRICATING & HYDRAULIC)
9320	RUBBER FABRICATED MATERIALS
9330	PLASTIC FABRICATED MATERIALS
9340	GLASS FABRICATED MATERIALS
9390	MISC. FABRICATED NONMETALLIC MATERIALS
95GP	METAL BARS, SHEETS & SHAPES
9505	WIRE, NONELEC., IRON & STEEL
9510	BARS & RODS, IRON & STEEL
9515	PLATE, SHEET & STRIP, IRON & STEEL
9520	STRUCTURAL SHAPES, IRON & STEEL
9525	WIRE, NONELEC., NONFERROUS
9530	BARS & RODS, NONFERROUS
9535	PLATE, SHEET & STRIP, NONFERROUS
9540	STRUCTURAL SHAPES, NONFERROUS
9545	PLATE, SHEET, STRIP, FOIL & WIRE, PRECIOUS METAL
9630	ADDITIVE METAL MATERIALS AND MASTER ALLOYS
9640	IRON & STEEL PRIMARY & SEMI-FINISHED PRODUCTS
9650	NONFERROUS REFINERY AND INTERMEDIATE FORMS
9660	PRECIOUS METALS PRIMARY FORMS

ASSIGNEE RESPONSIBILITY:

MECA	(J. GALLIVAN)
MFFP	(E. CLEGG)
NDTI	(J. QUIGLEY)
THJM	(H. KLEIN)
8010	(E. CLEGG)
8030	(E. CLEGG)
9640	(J. GALLIVAN)

VU-GRAPH 3

That brings us to 1977 when the Defense Science Board examined the DoD standardization activities and issued a report entitled "Report of the Task Force on Specifications and Standards" dated April 1977. Some of the major findings are shown in vu-graph 4. The major thrusts are to improve the climate of application, upgrade existing body of documents and to provide and maintain high level management attention.

Also in 1977, the National Materials Advisory Board (NMAB) examined that part of the DSP which dealt with materials and materials processing. The result was a report (NMAB Report No. 330) which detailed the following recommendations (vu-graph 5): a) exploit cost-effectiveness potential of standardization, b) increase DoD emphasis on specifications and standards, c) take advantage of voluntary standards system, d) work toward a unified system of specifications and standards, and e) use specifications and standards as a mechanism to cope with shortages, substitution and conservation.

REPORT ON TASK FORCE ON SPECIFICATIONS AND STANDARDS

SHEA REPORT, April 1977

SOME MAJOR FINDINGS:

- SPECIFICATIONS AND STANDARDS ESSENTIAL TO TECHNICAL PROCUREMENT
- PRESENT BODY OF MILITARY SPECIFICATIONS AND STANDARDS IS ADEQUATE TO THE NEEDS OF DoD
- SPECIFICATIONS AND STANDARDS CONTAIN CORPORATE HISTORY OF LESSONS LEARNED
- MAJOR PAYOFF FOR IMPROVEMENT IN SPECIFICATIONS AND STANDARDS WILL COME INITIALLY IN THEIR METHOD OF APPLICATION FOLLOWED BY LONGER RANGE IMPROVEMENTS IN CONTENT.

VU-GRAPH 4

MATERIALS AND PROCESS SPECIFICATIONS AND STANDARDS

NMAB REPORT 1977

SOME MAJOR FINDINGS:

- EXPLOIT COST-EFFECTIVENESS POTENTIAL OF STANDARDIZATION
- INCREASE DoD EMPHASIS ON SPECIFICATIONS AND STANDARDS
- TAKE ADVANTAGE OF VOLUNTARY STANDARDS SYSTEM
- WORK TOWARD A UNIFIED SYSTEM OF SPECIFICATIONS AND STANDARDS
- USE SPECIFICATIONS AND STANDARDS AS A MECHANISM TO COPE WITH SHORTAGES SUBSTITUTION AND CONSERVATION.

VU-GRAPH 5

DoD DIRECTIVE 4120.21, April 1977

TITLE: "SPECIFICATIONS AND STANDARDS APPLICATION"

SCOPE: REQUIRES ALL DoD COMPONENTS TO ESTABLISH SPECIFIC AND CONTINUING MANAGEMENT CONTROLS OVER THE UTILIZATION OF SPECIFICATIONS, STANDARDS AND RELATED TECHNICAL DATA IN THE ACQUISITION PROCESS TO ASSURE THEY ARE PROPERLY APPLIED AND TAILORED TO REFLECT THE MINIMAL ESSENTIAL REQUIREMENTS FOR THAT PARTICULAR SYSTEM.

VU-GRAPH 6

Both the Defense Science Board study, which examined the entire DSP, and the NMAB, which examined only those documents pertaining to materials and materials processes, have led to important new initiatives. I would like to discuss some of them now.

First, DoD Directive 4120.21 entitled "Specifications and Standards Application" issued during 1977 (vu-graph 6). The thrust here is not to treat the entire specification as sacred but to only use that portion of the document applicable, thereby reducing the cost of the item. This concept is known as "tailoring."

The second initiative is also in the form of an official DoD policy (DoD Instruction 4120.20, "Development and Use of Nongovernment Specifications and Standards") which is detailed in the next vu-graph (vu-graph 7). As you can see, emphasis is placed on the adoption and use of nongovernment documents as well as on participation in standards writing body activities such as American Society for Testing and Materials (ASTM). In other words, if there is a private sector document that is duplicating the military document, the latter should be cancelled. This is a tall order but some progress is being made as is shown on the next vu-graph (vu-graph 8). I should mention that the rate of adoption of private sector documents is not expected to increase indefinitely at the rate shown, since there is a finite number of documents that can be adopted. Therefore, the curve will probably bend over and level off.

The last initiative which I would like to cover this morning is one given the acronym CCAP standing for Commercial Commodity Acquisition Program. Additional details are provided on the next vu-graph (vu-graph 9). This initiative is still in the pilot stage emphasizing the procurement of items such as gasoline.

DoD INSTRUCTION 4120.20

December 1976

TITLE: "DEVELOPMENT AND USE OF NONGOVERNMENT SPECIFICATIONS AND STANDARDS"

SCOPE: PLACES GREATER EMPHASIS ON 1) ADOPTION OF NONGOVERNMENT SPECIFICATIONS AND STANDARDS, 2) USE OF NONGOVERNMENT SPECIFICATIONS AND STANDARDS IN THE DESIGN AND DEVELOPMENT OF MATERIEL, 3) DoD PARTICIPATION IN THE DEVELOPMENT AND ADOPTION OF NONGOVERNMENT DOCUMENTS IS PREFERRED TO THE DEVELOPMENT OF A NEW, REVISED MILITARY OR FEDERAL DOCUMENT, AND 4) DoD DEPARTMENTS AND AGENCIES ACTIVELY PARTICIPATE IN NONGOVERNMENT BODIES ENGAGED IN THE PROMULGATION OF NONGOVERNMENT DOCUMENTS.

VU-GRAPH 7

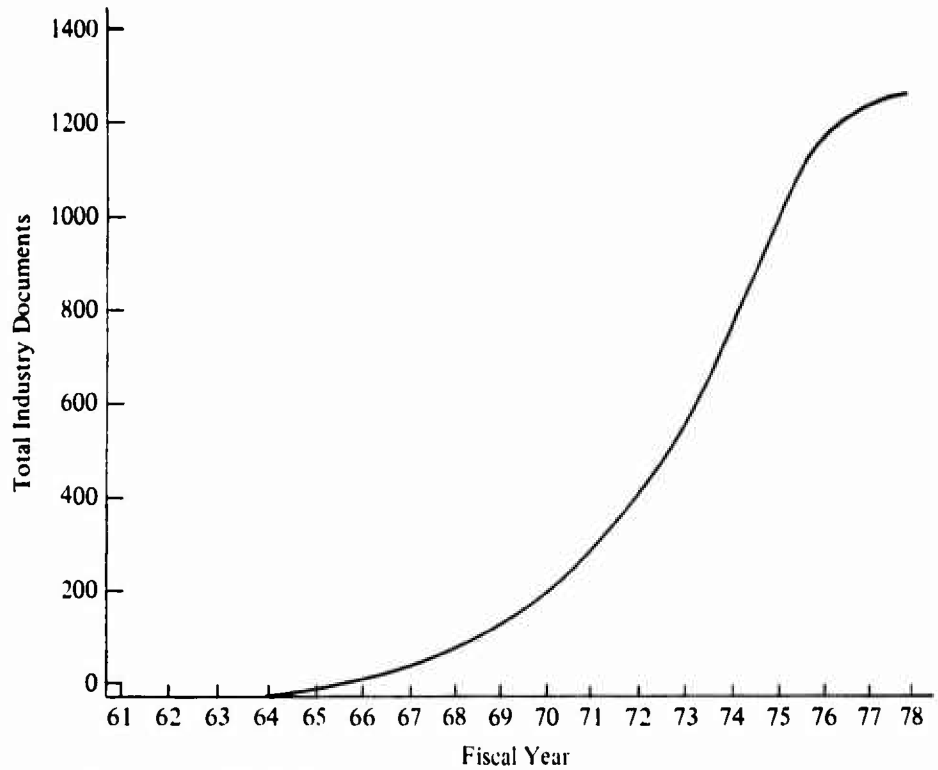


Figure 1. NUMBER OF INDUSTRY DOCUMENTS LISTED IN DODISS AS A FUNCTION OF TIME.

VU-GRAPH 8

OFPP STATEMENT

May 1976

TITLE: "COMMERCIAL PRODUCT ACQUISITION"

SCOPE: THE GOVERNMENT WILL PURCHASE COMMERCIAL, OFF-THE-SHELF PRODUCTS WHEN SUCH PRODUCTS WILL ADEQUATELY SERVE THE GOVERNMENT'S REQUIREMENTS, PROVIDED SUCH PRODUCTS HAVE AN ESTABLISHED COMMERCIAL MARKET ACCEPTABILITY.

ALSO, THE GOVERNMENT WILL UTILIZE COMMERCIAL DISTRIBUTION CHANNELS IN SUPPLY ING COMMERCIAL PRODUCTS TO ITS USERS.

VU-GRAPH 9

It should be noted that as part of a continuing effort to reduce cost, DoD has identified through the Defense Science Board report categories that are candidates for misapplication and misinterpretation. These cost driver areas are shown in the next vu-graph (vu-graph 10). From this, a list of FSC areas or classes that bear on these cost driver areas have been compiled and are shown in this vu-graph (vu-graph 11).

GENERAL COST DRIVER SPECIFICATIONS

- GENERAL DESIGN REQUIREMENT SPECIFICATIONS
- ENVIRONMENTAL REQUIREMENTS AND TEST METHODS
- RELIABILITY AND MAINTAINABILITY
- QUALITY CONTROL
- HUMAN FACTORS AND SAFETY
- DOCUMENTATION
- CONFIGURATION CONTROL
- INTEGRATED LOGISTIC SUPPORT
- PACKING, PACKAGING, PRESERVATION, TRANSPORT

VU-GRAPH 10

STANDARDIZATION COST DRIVER AREA ASSIGNMENTS
AND PROGRAM PLANNING

AREA	LEAD SERVICE	ASSIGNEE
RELIABILITY	DMSSO	DMSSO (SD)
ELECTROMAGNETIC COMPATABILITY	NAVY	NAVELEX (EC)
CONFIGURATION MANAGEMENT	NAVY	NAVMAT (NM)
DOCUMENTATION	(UNASSIGNED)	
QUALITY CONTROL/ASSURANCE	ARMY	ARRADCOM (AR)
NONDESTRUCTIVE TESTING & INSPECTION	ARMY	AMMRC (MR)
PACKING, PACKAGING, PRESERVATION & TRANSPORTABILITY	ARMY	TOBYHANNA (SM)
HUMAN FACTORS & SAFETY	ARMY	MIRADCOM (MI)
ENVIRONMENTAL REQUIREMENTS & RELATED TEST METHODS	AIR FORCE	AFSC/ASD (11)
GENERAL DESIGN REQUIREMENTS	AIR FORCE	AFSC/ASD (11)
THERMAL JOINING OF METALS	ARMY	AMMRC (MR)
SOLDERING	ARMY	MIRADCOM (MI)

VU-GRAPH 11

In this regard, one FSC class of importance, and one for which AMMRC has responsibility, is Nondestructive Testing and Inspection (NDTI). I would like to spend a few minutes describing the approach that we have taken in light of the above initiatives. The first step is to put together a time-phased program plan whose objective is detailed in the next vu-graph (vu-graph 12). One of the main ingredients here is to list for subsequent evaluation all documents that comprise the NDTI area. This has been done as shown in the next group of vu-graphs (vu-graph 13 - vu-graph 17).

DoD STANDARDIZATION AREA PROGRAM PLAN – NDTI

THE PROGRAM PLAN PROVIDES A TIME-PHASED DELINEATION OF TASKS REQUIRED TO OVERCOME OBSOLESCENCE, OVERLAP, AND VOIDS IN THE BODY OF MILITARY STANDARDIZATION DOCUMENTS DEALING WITH NON-DESTRUCTIVE TESTING AND INSPECTION (NDTI).

THE THRUST OF THIS DOCUMENT IS TO DEFINE, SCHEDULE, PLAN AND CONTROL THE NECESSARY STANDARDIZATION ACTIVITIES WITHIN THE DoD, AND TO REFLECT CONCURRENCE AND COMMITMENT BY THE SERVICES TO THE ACCOMPLISHMENT OF SPECIFIC ASSIGNMENTS WITHIN SCHEDULED MILESTONES.

VU-GRAPH 12

NDT STANDARDIZATION DOCUMENTS

INTRODUCTION

On the following pages are listed the more common standardization documents dealing with NDT. The listing is broken down into several groups relating to specific NDT areas. The areas identified are:

General

Radiography

Ultrasonics

Penetrant

Electromagnetic (Eddy Current)

Magnetic Particle

Leak Testing

The listing shown is as current and thorough as practicable (compiled as of March 1978). The reader is cautioned to first check the latest issue of the DODISS (or other applicable indexes of technical society publications) to ascertain availability and currency of any document referenced. A list of NDT standardization handbooks and pertinent quality assurancy pamphlets is included.

VU-GRAPH 13

GENERAL

MIL-STD-271	Nondestructive Testing Requirements for Metals. (Radiography, Magnetic Particle, liquid Penetrant, Leak Testing, Ultrasonics).
MIL-STD-798	Nondestructive Testing, Welding Quality Control, Material Control & Identification & Hi-Shock Test Requirements for Piping System Components for Naval Shipboard Use. (Radiography, Magnetic Particle, Penetrant).
MIL-I-6870	Inspection Requirements, Nondestructive for Aircraft Materials and Parts (Magnetic Particle, Penetrant, Radiographic, Ultrasonic, Eddy Current).
ASNT-TC-1A	Recommended Practice Nondestructive Testing Personnel Qualification & Certification. (Supplement A, Radiographic Testing; Supplement B, Magnetic Particle; Supplement C, Ultrasonic Testing; Supplement D, Liquid Penetrant; and Supplement E, Eddy Current).
AWS - A2.2-58	Nondestructive Testing Symbols (Replaces MIL-STD-231).
Air Force TO-00-25-224	Welding High Pressure and Cryogenic Systems (Section 4 – Nondestructive Inspection by Ultrasonic and Eddy Current Methods).
ASME	ASME Boiler and Pressure Vessel Code. Section I, Section III, Section VIII, Section IX, Division 2, and Section IV.
MIL-STD-410	Qualification of Inspection Personnel
ASTM	Index to ASTM Standards
ASTM	Book of Standards, Part 11
ASTM E543	Determining the Qualification of Nondestructive Testing Agencies

VU-GRAPH 14

PENETRANTS

(See General Section)

MIL-I-6866	Inspection; Penetrant, Method of.
MIL-I-25135	Inspection Materials, Penetrant (ASC).
MIL-F-38762	Fluorescent Penetrant Inspection Units.
Air Force T.O. 42c-I-10	Inspection of Materials; Fluorescent and Dye Penetrant Methods.
MSFC-STD-366	NASA Standard: Penetrant Inspection Method.
ASTM A462	Method for Liquid Penetrant Inspection of Steel Forgings.
ASTM B165	Standard Methods for Liquid Penetrant Inspection.
ASTM B270	Terms Relating to Liquid Penetrant Inspection.
AMS 2645	Fluorescent Penetrant Inspection.
AMS 2646	Contrast Dye Penetrant Inspection.
AMS 3155	Oil, Fluorescent Penetrant, Water Soluble.
AMS 3156	Oil, Fluorescent Penetrant, Water Soluble.
AMS 3157	Oil, Fluorescent Penetrant, High Fluorescence, Solvent Soluble.
AMS 3158	Solution, Fluorescent Penetrant, Water Base.

VU-GRAPH 15

ULTRASONIC

(See General Section)

MIL-STD-770	Ultrasonic Inspection of Lead.
MIL-I-8950	Inspection, Ultrasonic, Wrought Metals, Process for.
MIL-U-81055	Ultrasonic Inspection, Immersion, of Wrought Metal, General Specification for (Torpedo MK 46 MCD O).
NAVSHIPS 0900-006-3010	Ultrasonic Inspection, Procedure & Acceptance Standards for Hull Structure, Production Repair Welds.
AISI	Industry Practices for Ultrasonic Nondestructive Testing of Steel Tubular Products.
AISI	Ultrasonic Inspection of Steel Products.
Al. Assoc.	Ultrasonic Quality Limits for Aluminum Mill Products.
Al. Assoc.	Ultrasonic Standards for Plate, Extruxions and Forgings.
AMS 2630	Ultrasonic Inspection.
ASTM A578	Longitudinal Wave Ultrasonic Testing and Inspection of Plain and Clad Steel Plates for Special Applications.
ASTM E113	Ultrasonic Testing by the Resonance Method.
ASTM E114	Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves Induced by Direct Contact.
ASTM E127	Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks.
ASTM E164	Ultrasonic Contact Inspection of Weldments.
ASTM E215	Ultrasonic Inspection of Metal Pipe and Tubing for Longitudinal Discontinuities.

VU-GRAPH 16

RADIOGRAPHIC

(See General Section)

MIL-STD-139	Radiographic Inspection; Soundness Requirements for Aluminum and Magnesium Castings (For Small Arms Parts).
MIL-STD-437	X-Ray Standard for Rare Aluminum Alloy Electrode Welds.
MIL-STD-453	Inspection, Radiographic.
MIL-STD-746	Radiographic Testing Requirements for Cast Explosives.
MIL-STD-775	X-Ray Standards Welding Electrode Qualification and Quality Conformance Test Welds.
MIL-STD-779	Reference Radiographs for Steel Fusion Welds; Vol. I 0.030", 0.080" and 3/16"; Vol. II 3/8", 3/4" and 2.0"; Vol. III 5.0".
MIL-STD-1238	Radiographic Inspection; Soundness Requirements for Steel Castings (For Small Arms Parts).
MIL-STD-1257	Radiographic & Visual Soundness Requirements for Cobalt-Chromium Alloy Liners (For Small Arms Barrels).
Fed. Std. - No. S2	X-Ray Tube Focal Spot, Method of Measurement.
MIL-R-11468	Radiographic Inspection, Soundness Requirements for Arc and Gas Welds in Steel.
MIL-R-11469	Radiographic Inspection, Soundness Requirements for Steel Castings.
MIL-R-11470	Radiographic Inspection, Qualification of Equipment, Operators & Equipment.
NAVSHIPS 0900-003-9000	Radiographic Standards for Production and Repair Welds.
MIL-R-45774	Radiographic Inspection, Soundness Requirements for Fusion Welds in Aluminum & Magnesium Millise Components.
MIL-R-51060	Radioactive Test Sample, Strontium 90 and Yttrium 90, Beta, M6.
MIL-C-6021	Casting; Classification and Inspection of.
MIL-R-81080	Radiographic Inspection, Quality Levels for (Torpedo MK MOD O).

VU-GRAPH 17

Having done this, an analysis is performed where some important questions have to be asked. Do documents need updating? Have advances in NDT been included? Are there pertinent private sector documents? Is there overlap in documents? Is the CCAP program applicable here?

Perhaps a similar approach should be taken with regard to those FSC areas that pertain to tires and which are of interest to those of you in the audience this morning. These FSC areas are 2610 – Tires and Tubes, Pneumatic, Except Aircraft; 2620 – Tires and Tubes, Pneumatic, Aircraft; 2630 – Tires, Solid and Cushion; and 2640 – Tire Rebuilding and Tire and Tube Repair Materials.

From a quick examination of the DODISS, these FSC Classes (vu-graph 18) account for approximately 35 documents (vu-graph 19 - vu-graph 20). Obviously, we don't have time to discuss all of these documents. However, I did pick out three for comment:

MIL-T-12459C, Tire, Pneumatic: For Military Ground Vehicles. Examination reveals the plunger test is utilized as a quality assurance provision (vu-graph 21). Following the plunger test, the tire is then examined and a visual examination is then made for hidden defects. How much better it would be to utilize a true nondestructive test. From what I've heard this morning, some of these NDT type tests appear to be very promising and perhaps are ready for incorporation into standardization type documents.

MIL-STD 698A, Quality Standards for Aircraft Pneumatic Tires and Inner Tubes. With regard to aircraft tires, it is seen (vu-graph 22) that many defects for tire treads are mentioned. However, no reference standard is given for "moisture or air under the surface" as shown in vu-graph 23. How do we evaluate that particular defect?

The next example pertains to MIL-STD-1224, Visual Inspection Guide for Pneumatic Tires (Nonaircraft). Here, many figures (vu-graph 24 - vu-graph 27) are devoted to visually detected defects. However, how many of these are applicable to radial tires?

24GP	TRACTORS							
2410	TRACTORS, FULL TRACK, LOW SPEED	ME		YD	99	CS	CS	5
2420	TRACTORS, WHEELED	ME		YD	99	CS	CS	5
2430	TRACTORS, TRACK LAYING, HIGH SPEED	AT		YD	99		AT	5
							3	
25GP	VEHICULAR EQUIPMENT COMPONENTS							
2510	VEHICULAR CAB, BODY AND FRAME STRUCTURAL CMPTS	AT		YD	99	CS	CS	1
2520	VEHICULAR POWER TRANSMISSION COMPONENTS	AT		YD	99	CS	CS	1
2530	VEHICULAR BRAKE, STRG, AXLE, WHEEL AND TRACK CMPTS	CS	AT	YD	99		CS	1
2540	VEHICULAR FURNITURE AND ACCESSORIES	CS	AT	YD	99		CS	5
2590	MISCELLANEOUS VEHICULAR COMPONENTS	CS	AT	YD	99		CS	5
							5	
26GP	TIRES AND TUBES							
2610	TIRES AND TUBES, PNEUMATIC, EXCEPT AIRCRAFT	AT		YD	99		AT	1
2620	TIRES AND TUBES, PNEUMATIC, AIRCRAFT	99	AV	AS			99	1
2630	TIRES, SOLID AND CUSHION	A7		YD	99		A7	5
2640	TIRE REBUILDING AND TIRE AND TUBE REPAIR MATERIALS	A7		YD	99		AT	5

VU-GRAPH 18

	2610	Inner Tube, Pneumatic Tire USER-ME	ZZ-I-550E (2)	†	19 Mar 76			
	2610	Inner Tube, Pneumatic Tire	FED-STD-308B	†	01 Aug 77			
	2610	Tire And Rim Association, Year Book 1972	TRA-YB	99	08 Aug 72	AT	YD	99
L	2610	Tire, Pneumatic, With Flap, 14.00-20, Run Flat	MIL-T-62157	AT	07 Nov 72	AT		
	2610	Tire, Pneumatic Permissible Sizes And Loading For Use On Original Material Handling Equipment Validated Nov 70 USER-MC AS OS CS	MS-16968A	SA	28 Jun 65	GL	SA	99
L	2610	Tire, Pneumatic, For Truck, Logistical Goer Type (Tubeless)	MIL-T-62129A (1)	AT	12 Nov 76	AT		
	2610	Tire, Pneumatic, Large Size, Off-the-road, Special, 18.00-25, 12 Pr. Sand, Amphibious USER-MC REV AT	MIL-T-52583/1 (1)	ME	24 Apr 78	ME	YD	
	2610	Tire, Pneumatic, Large Size, Off-the-road, Special, 24.00-29, 16 Pr, Sand, Amphibious Validated May 70 USER-CE MC REV-AT	MIL-T-52583/2	ME	08 Sep 67	ME	YD	99
	2610	Tire, Pneumatic, Large Size, Off-the-road, Special, 36.00-41 Pr, Earthmover Amphibious Validated May 70 USER-CE MC REV-AT	MIL-T-52583/3	ME	08 Sep 67	ME	YD	99
L	2610	Tire, Pneumatic, And Inner Tube, Pneumatic Tire, Tire With Flap, Packaging Of 110276	MIL-T-004J INT AMD 3 (AT)	AT	11 Feb 76	AT		
	2610	Tire, Pneumatic, And Inner Tube, Pneumatic Tire, Tire With Flap, Packaging And Packing Of USER-AV MC REV-ME SM SA	MIL-T-4H	AT	23 Jan 75	AT	YD	99
	2610	Tire, Pneumatic, For Military Ground Vehicle Validated Feb 76 USER-ME REV-CS	MIL-T-12459C (2) INT. AMD6	AT	15 Aug 67	AT	YD	99
	2610	Tire, Pneumatic, Industrial USER-ME MC SA 26 REV EA	ZZ-T-410A (3)	AT	25 Feb 75	AT	YD	99
	2610	Tire, Pneumatic, Large Size, Off The Road, Special, Widebase 23-21 MI.	MIL-T-52583/4	ME	24 Apr 78	ME	YD	
	2610	Tire, Pneumatic, Large Size, Off-the-road, General Specification for USER-MC REV-AT	MIL-T-52583 (1)	ME	24 Apr 78	ME	YD	
	2610	Tire, Pneumatic, Vehicular (Highway Ligat Truck) USER-CE REV-AR YD	FED-STD-345	*AT	15 Mar 72	AT		
	2610	Tire, Pneumatic, Vehicular (Passenger Highway)	FED-STD-316A CHANGE 1 05 Apr 78	*AT	15 Nov 76	AT		
	2610	Tires, Pneumatic And Tires, Semipneumatic, Installed On Vehicles, Preparation for Storage Of Validated Nov 74 USER-MC REV-SM	MIL-T-46755A	AT	04 Sep 69	AT		99
Q	2610	Tires, Pneumatic, Agricultural	ZZ-T-1619B CHANGE 1 06 Jan 1978	†	15 Jul 77			
	2610	Tires, Pneumatic, Low Speed, Off Highway USER-CE REV-YD	ZZ-T-1083E	*AT	20 Aug 76	AT		
Q	2610	Tires, Pneumatic, Vehicle And Portable Equipment USER-CE	ZZ-T-381M (2) INT AMD-8	%	10 Jul 72			
	2610	Tube, Inner, Pneumatic, for Tires (Automobiles, Trucks, Motorcycles, And Other Ground Vehicles)	ZZ-T-721E	†	20 May 52			
	2610	Visual Inspection Guide for Pneumatic Tires (Non-Aircraft) Validated May 77 USER-ME	MIL-STD-1224 CHANGE 1 23 FEB 1961	AT	15 Sep 60	AT	YD	99
L	2620	Color Coding -age Identification Actf Tires	MS-27822A	99	07 Mar 72			99
L	2620	Identification Aircraft Tires By Colored Tape	MS-14113B	AS	29 Sep 75		AS	
	2620	Inner Tube, Pneumatic Tire, Aircraft	MIL-I-5014F (2)	99	16 Jan 78	AV	AS	99
	2620	Method of Dimensioning And Determining Clearance for Aircraft Tires And Rims Validated May 76 REV-99	MIL-STD-878A CHANGE 1 30 APR 1971	11	22 Oct 69	AV	AS	11
	2620	Quality Standards for Aircraft Pneumatic Tires, And Inner Tubes USER-MC REV-99.	MIL-STD-698B	AV	15 Jul 77	AV	AS	11
L	2620	Reguilt Tire-aircraft 22X5.5 (200 Mph) Type Vii (Navy)	MS-14142	AS	31 Jan 73		AS	
Q	2620	Repair And Reguilding Of Used Aircraft Pneumatic Tires REV-GL 11	MIL-R7726F (T) SUPP I	99	10 May 78	AV	AS	99
L	2620	Retread Tire - Aircraft 20.00-20 (200 Mph) Type Ii (Navy) Validated Mar 75	MS-3389	AS	18 Feb 69		AS	
L	2620	Retread Tire - Aircraft 26 X 6.6 (200 Mph/high Performance) Type Vii (Navy) Validated Mar 75	MS-3383	AS	18 Feb 69		AS	
L	2620	Retread Tire - Aircraft 28 X 7.7 (200 Mph) Type Vii (Navy) Validated Mar 75	MS-3384	AS	18 Feb 69		AS	
L	2620	Retread Tire - Aircraft 28 X 9.0 (173 Mph) Type Vii (Navy) Validated Mar 75	MS-3385	AS	18 Feb 69		AS	
L	2620	Retread Tire - Aircraft 36 X 11 (200 Mph) Type Vii (Navy) Validated Mar 75	MS-3386	AS	18 Feb 69		AS	
L	2620	Retread Tire - Aircraft 40 X 14 (200 Mph) Type Vii (Navy) Validated Mar 75	MS-3387	AS	18 Feb 69		AS	
L	2620	Retread Tire - Aircraft 44 x 13 (200 Mph) Type Vii (Navy) Validated Mar 75	MS-3388	AS	18 Feb 69		AS	
L	2620	Retread Tire-aircraft Laboratory Quality Assurance Requirements	MS-3377A	AS	09 Jun 75		AS	
L	2620	Retread Tire-aircraft 18X4.4 (200 Mph) Type Vii (Navy) Validated Mar 75	MS-3378	AS	18 Feb 69		AS	
L	2620	Retread Tire-aircraft 18X5.7 (247 Mph) Type Vii (Navy) Validated Mar 75	MS-3379	AS	18 Feb 69		AS	
L	2620	Retread Tire-aircraft 20X5.5 (200 Mph/high Performance) Type Vii (Navy) Validated Mar 75	MS-3380	AS	18 Feb 69		AS	
L	2620	Retread Tire-aircraft 26X6.6 (200 Mph) Type Vii (Navy) Validated Mar 75	MS-3382	AS	18 Feb 69		AS	
L	2620	Service Suitability (Flight) Testing Of Rebuilt Navy Aircraft Tires	MS-14147	AS	13 Jan 76		AS	
L	2620	Tire - Aircraft, 11.00-10, Type Iii (Navy) Validated Dec 71	MS-90444	AS	02 May 66		AS	
L	2620	Tire - Aircraft, 13.5 X 6.00-4 (Navy)	MS-14158	AS	16 Oct 74		AS	
L	2620	Tire - Aircraft, 20 X 5.5 Type Vii (Navy Validated Nov 73	MS-26540A	AS	12 Feb 68		AS	
L	2620	Tire - Aircraft, 22 X 6.6-10 (New Design)	MS-14168	AS	21 May 76		AS	
L	2620	Tire - Aircraft, 26 X 7.75-13 (Navy)	MS-14159	AS	16 Oct 74		AS	
L	2620	Tire - Aircraft, 28 x 7.7 - (200 Mph) Ft- Type Vii (Navy) Tubeless Validated Dec 73	MS 17838	AS	24 Aug 62		AS	
L	2620	Tire - Aircraft, 37 X 11.5 - 16, Type Vii (Navy)	MS 14152A	AS	23 Jan 78		AS	
L	2620	Tire - Aircraft, 7.50-10 Channel Trend Application, OV-10 Nose Landing Gear Only Validated Apr 76	MS-3502	AS	24 Mar 70		AS	
L	2620	Tire Pneumatic Rebuilt Type Viii 30 X 11.5-14.5/24 Pr	MS-87953	99	28 Mar 78		99	

VU-GRAPH 19

L	2620	Tire Pneumatic Rebuilt, Type Iii 12.50-16.12 Pr	MS-22080	99	10 Jun 77		AS	99
L	2620	Tire Pneumatic Retread Type Vii 56 X 16.24 Pr	MS-27812	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Vii 20 X 4.4 / 12 Pr	MS-27821B	99	12 Nov 73			99
L	2620	Tire Pneumatic Retread, Type Vii 30 X 8.8 / 22 Pr	MS-27819	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Vii 36 X 11 /22 Pr	MS-27817A	99	01 Apr 78			99
L	2620	Tire Pneumatic Retread, Type Vii 38 X 11 / 14 Pr	MS-27818A	99	01 Apr 78			99
L	2620	Tire Pneumatic Retread, Type Vii 49 X 17/26 Pr	MS-27811A	99	01 Apr 78			99
L	2620	Tire Pneumatic Retread, Type Vii 56 X 16 / 34 Pr	MS-27816	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Vii 56 X 16 % 38 Pr. 250 Mph	MS-27813	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Vii 56 X 1632 Pr	MS-27814	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Viii 31 X 11.50 - 16/22 Pr	MS-27820	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type VII 44 X 16, 28 Pr	MS-27815B	99	01 Apr 78			99
	2620	Tire Pneumatic Type Vii 20 X 4.4/12 Pr	MS-22076	99	10 Jun 77		AS	99
	2620	Tire Rebuilt 26 X 6.6/14 Pr	MS-22078	99	10 Jun 77		AS	99
L	2620	Tire-aircraft 20 X 5.5 Type Vii (Navy) Validated Feb 75	MS-3374	AS	20 Dec 68		AS	
L	2620	Tire-aircraft, 24 X 5.5 (200 Mph) Fabric Tread Type Vii (Navy) Validated Feb 75	MS-18060A	AS	17 Dec 67		AS	
L	2620	Tire-aircraft, 26 X 6.6 (200 Mph) Type Vii (Navy) Validated Apr 74	MS-26564A	AS	15 Jun 67		AS	
L	2620	Tire-aircraft, 40 X 14 (200 Mph) type Vii (Navy) Validated Nov 73	MS-26563A	AS	14 Jul 67		AS	
L	2620	Tire-casing - Aircraft, 24 X 5.5 Type Vii (Navy) Validated Nov 73	MS-26526B	AS	1 Dec 61		AS	
	2620	Tire-pneumatic Rebuilt, Type Vii 20.00 20/26 Pr	MS-27823A	99	28 Sep 77		AS	99
	2620	Tire-pneumatic Type Iii 12.50-16/12 Pr	MS-22079	99	10 Jun 77		AS	99
L	2620	Tire/casing - Aircraft, 18 X 5.5 Type Vii (Navy) Validated Nov 73	MS-26535A	AS	1 Dec 61		AS	
L	2620	Tire/casing - Aircraft, 20 X 4.4 Type Vii (Navy)	MS-27538B	AS	20 Jun 75		AS	
L	2620	Tire/casing - Aircraft, 22 X 5.5 Type Vii (Navy) Validated Nov 73	MS-26539A	AS	1 Dec 61		AS	
L	2620	Tire/casing - Aircraft, 22 X 8.8 Type Vii (Navy) Validated Nov 73	MS-26537A	AS	1 Dec 61		AS	
L	2620	Tire, Aircraft 22 X 6.75-10 135 Knots (Navy)	MS-14161	AS	25 Nov 74		AS	
L	2620	Tire, Aircraft, 26 X 8.75-11 (Navy)	MS-14160	AS	16 Oct 74		AS	
L	2620	Tire, Aircraft, 28 X 9.0 Type Vii (Navy)	MS-90443B	AS	31 Jul 74		AS	
L	2620	Tire, Casing - Aircraft, 24 X 7.7 Type Vii (Navy) Validated Nov 73	MS-26558A	AS	1 Dec 61		AS	
L	*2620	Tire, Pneumatic - Aircraft, 25 X 6.0 Type Vii (Navy)	MS-26543A	AS	08 Apr 75		AS	
	2620	Tire, Pneumatic New Type Iii 20.00-20.26PR	MS-22081	99	10 Jun 77		AS	99
	2620	Tire, Pneumatic, New Type Vii 26 X 6.6/14 Pr	MS-22077	99	10 Jun 77		AS	99
L	2620	Tire, Pneumatic-helicopter Ground Handling, 3.50-6 Validated Feb 77	MS-87013	AV	29 Jun 64	AV		
Q	2620	Tire Pneumatic Aircraft USER-MC REV 99	MIL-T-5041G (1)	11	04 Mar 77	AV	AS	11
L	2620	Tire, Pneumatic, Aircraft 30X11.50-14.50, Type Viii(Navy) Fabric Reinforced Tread	MS-14171	AS	22 Dec 76		AS	
L	2620	Tire, Pneumatic, Aircraft, Rebuilt, 30 X 11.50-14.50, Type Viii (Navy) Fabric Reinforced Tread	MS-14172B	AS	12 Dec 77		AS	
L	2620	Tire, Pneumatic, Aircraft, Rebuilt, 30 X 8.0-16.00, Type Vii (Navy) Fabric Reinforced Tread	MS-14176	AS	13 Jan 77		AS	
L	2620	Tire, Pneumatic, Aircraft, Rebuilt, 27 X 11.5 - 16, Type Vii	MS-14170A	AS	23 Jan 78		AS	
L	2620	Tire, Pneumatic, Aircraft, 24 X 6.5-14 Fabric Reinforced Tread (200 Knots)	MS-14178	AS	11 Apr 78		AS	
L	2620	Tire, Pneumatic, Aircraft, 26 X 6.6, Type Vii (Navy)	MS-26533D	AS	09 Feb 78		AS	
	2620	Tire, Pneumatic, Aircraft, 34 X 9.9-16	MS-14162	AS	06 Mar 75	AV	AS	99
L	2620	Tire, Pneumatic, Aircraft, 36 X 11 High Speed, Type Vii (Navy)	MS-90346A	AS	31 Jan 78		AS	
	2620	Tire, Pneumatic, Aircraft, 44X13 High Speed-type Vii	MS-26557A	AS	27 May 75		AS	99
	2620	Tire, Pneumatic, Rebuilt, Aircraft, 34 X 9.9-16	MS-14167	AS	17 Feb 76	AV	AS	99
L	2620	Tread Tire-aircraft 24X5.5 (200 Mph) Type Vii (Navy) Validated Mar 75	MS-3381	AS	18 Feb 69		AS	
	2630	Tire, Cushion Permissable Sizes And Loading For Use On Original Material Handling Equipment Validated Nov 70 USER-MC AS OS CS	MS-16966A	SA	28 Jun 65	GL	SA	99
	2630	Tire, Solid Permissible Sizes And Loading for Use On Original Material Handling Equipment Validated Nov 70	MS-16967A	SA	28 Jun 65		SA	99
	2630	Tire, Solid Rubber, And Wheels, Solid Rubber Tire, (Industrial) Validated Apr 74 USER-MD MC REV-AT	ZZ-T-391D	/ME	11 Dec 70	ME	YD	99
Q	2630	Tire, Solid Rubber, And Wheels, Solid Rubber Tires Validated May 75 USER-ME MC REV-MI	MIL-T-3100B	AT	22 Apr 63	AT		99
L	2630	Wheel, Solid Rubber Tires, Rebuild Of USER-ME	MIL-W-46759A (1)	AT	10 May 74	AT		
	2640	Adapter, Pneumatic Tire Valve - Liquid	MIL-A-28677	YD	10 Sep 73		YD	99
L	2640	Cement, Thread, Rubber	MIL-C-42123	AT	18 Feb 70	AT		
	2640	Compound, Lubricating, Inner Tube, Aircraft Tire Validated Dec 70 USER-ME-REV-IS	MIL-C-5024A (1)	99	02 Jun 65		AS	99
L	2640	Lubricant, Mold, Tire, Silicone Base Emulsion Validated Jul 75 REV-EA	MIL-L-3921A	AT	05 Jan 71	AT		
	2640	Lubricant, Tire And Rim, Demounting, Validated Feb 76 USER-ME MC REV-AV AS	MIL-L-8362C	99	10 Oct 68	AT	YD	99
	2640	Patch, Pneumatic Tire Repair - Semi-cured Nylon Validated Mar 77 USER-MC	MS-52124	AT	22 Sep 72	AT	YD	99
	2640	Patch, Pneumatic Tire Repair, Chemical Cured Nylon And Vulcanizing Fluid Validated Mar 77	MS-52123	AT	22 Sep 72	AT	YD	99
	2640	Patch, Pneumatic Tire Repair, Uncured Validated Sep 76 USER-MC	MS-51312	AT	16 Jul 59	AT	YD	99
	2640	Patch, Repair, For Inner Tubes and Tubeless Tire Liners USER CS REV-AR	ZZ-P-112D (1)	/AT	27 Jul 74	AT	YD	99
L	2640	Repair Kit, Puncture, Pneumatic Tire REV-SM ME	MIL-R-45949A	AT	23 May 77	AT		
	2640	Tire, Pneumatic, Retread And Repair Materials	ZZ-T-416G	/AT	26 Sep 75	AT	YD	99
	2640	Tire, Pneumatic, Retreaded And Repaired REV-MC	ZZ-T-441D (3)	*AT	15 Feb 77	AT	YD	99
L	2640	Tread Rubber, for Recapping Pneumatic Tires, And Solid Rubber Tires for Industrial And Track Laying Vehicles, Packaging and Packing Of, Validated May 76	MIL-T-13584B	AT	30 Apr 76	AT		
	2640	Tread Rubber, Solid Rubber Tire For Track Laying Vehicles USER-MC	MIL-T-45301B INT AMD I (AT)	AT	20 Nov 75	AT	YD	99
L	2640	Tread Rubber, Strip Form Stock, For Retreading Tires Validated Nov 74	MIL-T-62118	AT	22 Sep 99	AT		
QL	2640	Valve Care, Pneumatic Tire, Inner Tube and Tubeless, Aircraft REV-CS	MIL-V-27317 (2)	99	24 Mar 78			99
	2640	Valves And Valve Spuds Caps And Cores, Pneumatic Tire USER-ME AS OS MC CG SH	ZZ-V-25D (2)	*AT	20 Sep 77	AT	YD	99

VU-GRAPH 20

4.5.2.4.4 Thickness. After the tire has been cut to determine hidden defects (see 4.5.3.2), the thickness of the sidewalls and undertread shall be measured in accordance with method 2011, 2021, or 2121 of Standard FED. TEST METHOD STD. NO. 601.

4.5.3 Breaking energy and hidden defects.

4.5.3.1 Breaking energy plunger test.

4.5.3.1.1 Procedure. After the mounted tire in 4.5.2.4 has been measured as specified in 4.5.2.4.1 through 4.5.2.4.3 inclusive, a cylindrical steel plunger, 1¼ inches in diameter and hemispherical at the working end, shall be forced into the center of the tread portion of the inflated tire at the rate of 2 inches per minute to determine the force and penetration at break. Five measurements of force and penetration at break shall be made at points equally spaced around the circumference of the tire. In the event that the tire fails to break before the plunger is stopped by reaching the rim, the force and penetration shall be taken as this occurs. The energy value to determine conformance to 3.5 and table IV shall be calculated from the average values at break using the following formula:

$$W = \frac{FxP}{2}$$

Where W = energy at break, inch pounds.
F = force at break, pounds.
P = penetration at break, inches.

4.5.3.2 Hidden defects. After the plunger test has been made, the tire shall be subjected to visual inspection to visual inspection for hidden defects. This shall be done by cutting the tire in ten radial sections, with each section being cut, circumferentially, in midcrown and on each side of crown, near breaker edge at point of maximum shoulder thickness; any additional cuts deemed necessary for complete inspection of the tire shall be made. The cut sections shall then be inspected for evidence of separation of tread, ply, cord, or bead.

4.5.4 Tensile strength and elongation. After being checked for hidden defects the tire shall be subjected to tests for tensile strength and ultimate elongation of tread and sidewall, to determine conformance to 3.6 and 3.7 respectively.

4.5.4.1 Preparation of test specimens. Test specimens shall be cut (longitudinally at center of tread or sidewall) with a die No. VII of method 4111 of Standard FED. TEST METHOD STD. NO. 601. On tread specimens, the nonskid portion shall be sliced off with a knife, after which the central portion shall be buffed on each side over a length of 2½ inches until free from friction compound, fabric impressions, or irregularities of surface. In case specimens cut with die No. VII cannot be obtained, specimens may be cut with a die No. IV of method 4111 of the same standard. On sidewall specimens, rubber solvent shall be used, if necessary, to separate rubber and fabric and one or both sides shall be buffed as necessary. For class MR tread test specimens, tread shall be removed from wire.

VU-GRAPH 21

CONTENTS

TABLES

VU-GRAPH 22

TABLE I. – Classification of defects in accordance with Standard MIL-STD-105.

Categories	AQL percent defective	Items	Defects	Paragraph or specification reference
MAJOR:	1	Tire treads:		
101			Moisture or air under surface is unacceptable.	
102			Open tread splice whre immediately below tread splice there is a hollow area in the carcass.	5.2.2.2
103			Porosity in tread ribs is unacceptable.	
104			Cord outline visible in tread grooves (unacceptable except in special-purpose tires which were qualified with that condition).	5.3.1
105			Mold flash or rind at tread register: (a) Tires from open or cocked molds with a depression in the carcass. (b) Tires from open or cocked molds where tread flash thickness exceeds: Tire cross section — Open register 8 inches or less — 0.06-inch More than 8 inches and less than 15 — 0.13-inch 15 inches and longer — 0.18-inch	5.2.2.1
106			Off-register molds (tires from off- or out-of-register molds wehre radial stepoff, at tread rib, between the two halves, exceeds 0.03-inch).	5.2.2.1

VU-GRAPH 23

CONTENTS

FIGURES

VU-GRAPH 24

FIGURES–Continued

Figure

VU-GRAPH 25

FIGURES–Continued

Figures

VU-GRAPH 26

FIGURES–Continued

TABLES

VU-GRAPH 27

Standardization has brought us a long way in this country, and is responsible in large part for the standard of living we enjoy today. However, the time is ripe to upgrade the standardization effort. I believe that the current directions described in this presentation will do just that and result in long range beneficial effects on the entire DoD standardization effort. However, it will require top management's continuing support to sustain the momentum that has been initiated. Both ingredients are necessary to insure that Gillette's criterion of specification ("What the buyer needs and what the vendor is willing to sell him.") are met.

DISCUSSION OF THE NEED FOR SOME STANDARDIZATION IN THE FIELD OF NDT OF TIRES

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ABSTRACT

Non Destructive Inspection of tires has become a fundamental part of tire development. There are many different techniques, each employing various basic principles and methods of inspection and also utilizing numerous types of equipment. There are equally as many directions and goals being pursued and answers being obtained.

Is it possible that this is the time for the introduction of a standard to obtain a common language and set a realistic goal for the good of consumers, suppliers, manufacturers and inspectors?

During the initial phase of tire development there have been found numerous general categories of irregularities which can conceivably exist in a complex tire of today. Considering the various components, multiple belts and plies and the significant locations in a tire, there can exist an impracticable number of individual inspections which would be required to detect and identify each potential irregularity.

With some exceptions, each anomaly has a direct or indirect bearing on the overall performance of the tire. Depending on its degree of severity, it would be difficult to classify these as to their importance.

To detect a large variety of these conditions, there exist a multiplicity of industrial Non-Destructive Inspection (NDI) pieces of equipment. All of these methods of NDI have been found, from our experience, to have significant present limitations, along with their attributes. There simply does not yet exist a single Panacea NDI technique.

Consider the following:

X-ray is a vital and presently irreplaceable technique for technique for detecting blows, and defining geometric placements and conditions of beads, belts, plies, and many components. It is our experience, however, that X-ray is greatly limited in locating many critical thin line ply and belt separations as well as other irregularities detected by other methods.

Experience with ultrasound techniques indicates excellent potential for various areas of tire inspection. These include, but are not limited to, the measurement of gauge variation, location of foreign material and separations.

Due to the wide variations in acoustical impedance between certain materials, however, there has been considerable difficulty in detecting specific critical separations and other irregularities.

There is also a wide variation in potential use and limitations of reflective vs. thru techniques for ultrasonics.

Holography or Holographic Interferometry can be used to detect separations and locate their position and depth within acceptable limits. It also can be used to detect gross non uniformities, under certain conditions, and other anomalies.

Holography is not without its limitations. In the bead area, and turn-up region of a tire, holography can be ambiguous, time consuming and lacking correlation for many tire constructions. Holography is limited when utilized to determine the severity of a non uniformity of a new tire or in cases of multiple non uniformities.

In essence, most popular NDI techniques have considerable merit and value and while their coverage may overlap, many significant anomalies will escape one or the other or all techniques.

I would like to make a crude analogy between a tire and the physical make up of a human being. To predict a tire's life span is akin to expecting a doctor to predict a life span of a baby at birth. There are obvious tell-tale signs in rare cases which may be reason for concern. But it would be a monumental and probably an insurmountable task to achieve a single test which would guarantee a life expectancy of either. It would be difficult to diagnose a heart murmur using an encephalogram or a brain tumor using a stethoscope. Just as there are well established medical tests to diagnose various diseases, there is also, based on experience, specific NDI techniques to diagnose some of the various tire syndromes.

If it were known to a doctor that the new born infant was to be a long distance runner or was to survive in an environment requiring superhuman stamina, as that required of a high performance tire, he may be directed to performing tests with fairly conclusive evidence of survivability. This may also be the case with specific types of tires.

For the sake of discussion, consider the separation. Separation growth during service may or may not correlate with durability. Separations may grow, remain dormant, grow and become dormant, or even diminish in size, for some passenger tires for example, with increased mileage.

A distinct advantage that the tire companies have in evaluating NDI techniques is in the development stage of the tire design. Many experimental passenger and truck tire designs which are thwarted because of poor road and lab wheel test results indicated excellent correlation to various NDI techniques which were used to monitor the tire during its test cycle. Contrary to this, many passenger tires which pass exhaustive road and wheel testing generally indicate poor correlation to NDI techniques when monitored regardless of the anomalies they may develop.

Not all irregularities are detected or identified by the most popular methods of NDI. There are numerous techniques applied when specific problems are suspected.

It would be a mistake and a step backward to propose or single out a unique method of NDI. This would indicate an over reliance on that method and possible subjugation of other valuable methods, thus relaxing an overall vigilance required to produce a quality tire.

We then come to the problem of attempting to establish standards. The mere fact that there are nearly 275 methods of NDI or NDT used to assist in providing some quality assurance for over 700,000 tires manufactured per day, suggests that setting standards may be premature. Yet the mere numbers involved also imply that some type of standard is desirable if we are to obtain continuity and give direction to the NDI equipment manufacturers.

Then I ask, what type of standard would not be premature?

I would propose as a beginning to establish a glossary of terms which would at least result in a common language.

As a second step, I would propose a calibration sample, similar to a stepped block used in X-ray. The stepped block could be improved to incorporate various construction techniques similar to that used in a tire. Programmed flaws of all types could be built into blocks and these blocks could be available to the various NDI equipment manufacturers.

As a third step, I would propose eventually extending this technique to a series of calibration tires of contemporary design. Flaws could then be built into these tires for final evaluation of equipment. The type of calibration tires could include, but not be limited to, passenger, truck, airplane, military and retread tires.

There would be a multitude of problems realized with such a proposal. Obtaining a manufacturer and agreeing on construction, type of flaws, etc. would only be a few; however, I do believe it would be a worthwhile adventure and a beginning.

ULTRASONIC TIRE INSPECTION

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ABSTRACT

For the past several years, TARADCOM has been involved in various ultrasonic, holography and radiography tire inspection evaluation programs. The primary objective of the tire testing program is to eliminate or minimize defective tires, which would fail prematurely, from entering the retread system. Based on cost, safety, hardware required to perform the testing, and other considerations, the best inspection technique to meet the Army's needs is considered to be pulse-echo ultrasonic testing of tires. Therefore, the TARADCOM Product Assurance Directorate's Tire Inspection efforts have been concentrated in this area of NDT of tires. The plans for the current and future TARADCOM Tire Inspection Programs, which have been initiated to solve specific problems and satisfy particular user hardware requirements, will be discussed.

INTRODUCTION

Tire degradation is defined as a defective rubber to cord bond or the unraveling of the cords themselves. Detection of degraded tires is impossible by visual inspection of a retread candidate tire. The result of retreading a tire with degraded cord structure is premature failure of the retread tire. Early failures relate to lost investments. In most cases the cost of shipping the tires to the retreading facility is not recoverable. The same is true for the expenses for material and labor expended on tires that fail during retreading or are rejected after retreading. Only a portion of the expenses of retreading a tire are recovered for tires that fail in the field before they reach their useful life expectancy. However, these premature failures pose not only a dollar loss to the Army, but also create a potential safety hazard for the personnel operating the vehicle on which the tires fail.

FIGURE 1

In response to these problems, hardware requirement definitions for two different types of tire testing equipment have been generated (Figure 1). An inexpensive, easy to use tire tester is needed for posts, camps, and stations to inspect tires before they are shipped to the retreading facilities. This tester must require minimal operator action and must provide a single digital output on which the decision to ship the tire or not would be automatic. For the depots that have the tire retreading mission, more sophisticated tire inspection equipment is required for both pre and post retreading inspection. The tire inspection equipment would be utilized in the pre-retread area to monitor ultrasonic readings in relation to tire casing suitability for retreading. The post retread ultrasonic inspection equipment would be used to inspect for retread quality. Operator training and test result interpretation would be required for most retread inspection with the ultrasonic equipment.

TARADCOM has focused its attention on one pulse-echo ultrasonic tester which has been developed during this program and which has the potential to satisfy both these equipment requirements. However, before our NDT evaluation plans are discussed, a brief background of prior TARADCOM programs will be presented.

BACKGROUND (Figure 2)

Since its inception, the ultrasonic tire inspection development effort has been in conjunction with and under contract to General American Research Division (GARD). In mid-1973, the effort began with laboratory tire testing with a pulse-echo tire scanner at the GARD facility in Niles, Illinois. From this initial effort a single transducer ultrasonic tire inspector, which we call the Big Red Machine, was fabricated and utilized during two separate evaluations, one at Red River Army Depot (RRAD) and the other at GARD. The GARD evaluation involved testing 500 used tires ultrasonically and correlating the measurements to peel tests and optical examinations. The results of the 500 tire test revealed the requirement to inspect the tires at

TARADCOM
ULTRASONIC TIRE INSPECTION
BACKGROUND

JOINT TARADCOM AND GARD EFFORTS

- LABORATORY TIRE TESTING
- RRAD COMMENTS
- 500 TIRE TESTS

→ BIG RED TOO COMPLEX, EXPENSIVE AND TIME CONSUMING

⇒ HYGROSCOPIC PROPERTIES — DEGRADATION CONCEPT
YPG ROAD TEST — PROOF OF TIRE DEGRADATION

GARD DEVELOPMENT EFFORT

- ULTRASONIC CONTACT INSPECTION TECHNIQUE GENERATION
- TDM DEVELOPMENT

FIGURE 2

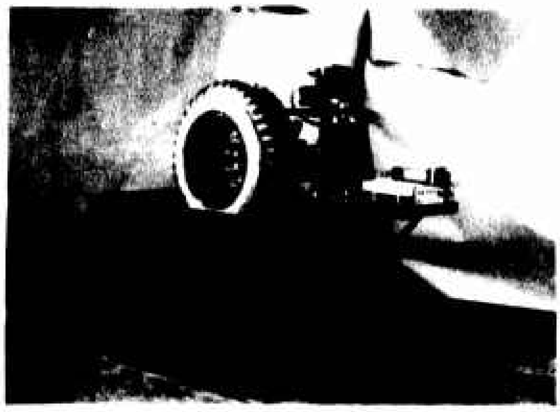

FIGURE 3

at both tire shoulders and the midline. This requirement and user comments from the RRAD evaluation were incorporated into an engineering prototype (Figure 3) which utilized three transducers for inspection of the shoulders and midline and a tire controller. The tire controller (Figure 4) sequenced the setting of the tire and the firing order of the transducers.

A parallel GARD effort to the 500 tire test on hygrosonic properties of or water effects on tires revealed that water absorbing tires also had low ultrasonic readings. Peel tests on these water absorbing tires verified a degraded cord structure state. This discovery inspired the birth of the degradation measurement concept. Two reports, "Ultrasonic Inspection for Tire Retreadability" and "Water Effect on Tire Maintenance Expenditure Limits," document the 500 tire test and the hygroscopic evaluations, respectively. During these evaluations pulse-echo tire inspection with the Big Red Machine was shown to be somewhat complex, expensive and too slow for high rate production testing of retread tires; however, the degradation concept was still as yet unproven in early 1975 to abandon the program to ultrasonically inspect tires for both local and circumferential defects with Big Red.

The hypothesized concept of tire degradation had to be verified. The existence of tire degradation was substantiated during a Yuma Proving Grounds (YPG) evaluation. A modified portable sonics unit (Figure 5) was used at YPG to follow ultrasonic tire measurements as a function of tire mileage during a vehicle road test. The data from this test showed that a tire mileage increased, the average tire degradation measurement decreased for both new and retread tires (Figure 6). At this time no further consideration was given to the deployment of the big red ultrasonic system because of the hardware inspection complexities, and because the circumferential defect, that is degradation, appeared to be the tire characteristic best able to indicate casing suitability for retreading.

FIGURE 4

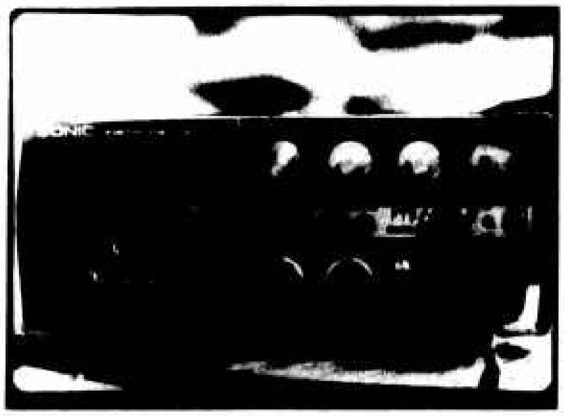

FIGURE 5

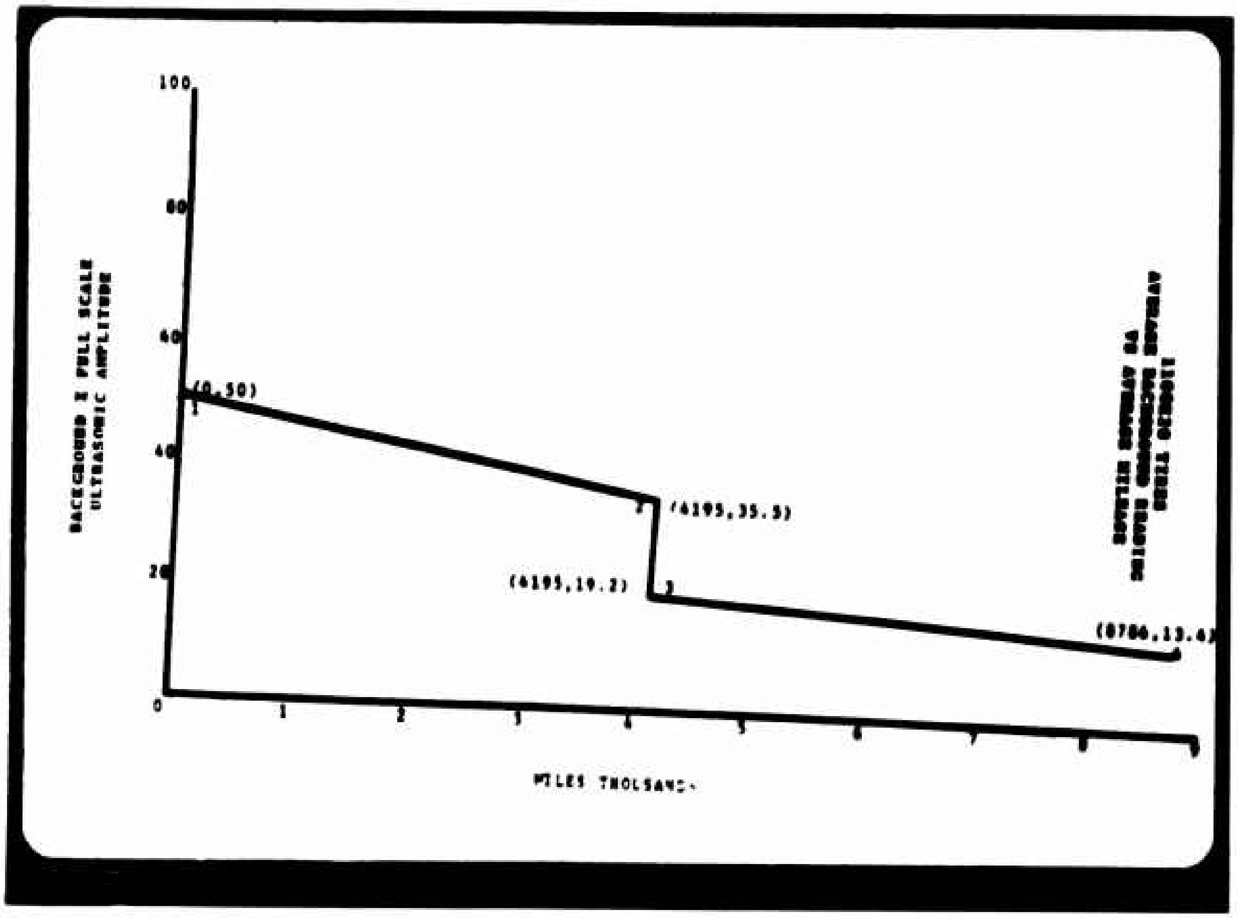

FIGURE 6

Since the time of the YPG road test, development and refinement of ultrasonic contact tire inspection techniques continued. This effort included transducer selection, generation of calibration standards, and further modification to the pulse-echo ultrasonic unit. From the contact tire inspection development effort, there evolved a commercially available single digital output tire inspection device, the tire degradation monitor (TDM) (Figure 7). The usage of the TDM became the central issue of the TARADCOM ultrasonic tire inspection program.

FIGURE 7

EVALUATION PROGRAMS

As stated, the ultrasonic equipment has evolved from the use of a pulse-echo tire scanner to a combination of modified sonics unit used in conjunction with a tire controller in the big red machine to a commercially available tire degradation monitor (TDM) with scope output capability. Therefore, the current TARADCOM programs are oriented to the evaluation of the TDM and to qualifying the degradation principle. Of the two current programs, one at RRAD and the other at YPG, each has its own objectives but both have been implemented to provide preliminary information

for accomplishment of the objectives of the final ultrasonic inspection evaluation, scheduled for initiation at the Army Maintenance Plant at Ober-Ramstadt next year.

RRAD EVALUATION SUMMARY (Figure 8)

The TDM is being utilized at RRAD to determine the ultrasonic tire inspection related savings which can be attributed to reduced tire casing failures during the retreading process or to fewer rejected tires after retreading.

A program work directive (PWD) for retreading 3,000 1100 x 20 tires has been issued to RRAD, which has also been funded to ultrasonically inspect these tires. The inspection personnel have been trained in the operation of the ultrasonic tire inspection equipment and a pilot inspection program on 50 tires has been completed. Results from this pilot program will be used to minimize any problems that might have arisen during the 3,000 tire inspection program, which is anticipated to start in June 1978. The inspection data will be collected, summarized, analyzed and compiled into a final report by 1979.

YPG EVALUATION SUMMARY (Figure 9)

The evaluation will be run as a TDM pilot program to assure that the data collected at Ober-Ramstadt, to determine remaining useful life of a retread tire in relation to the tires' degradation readings, will be statistically sufficient. In addition, the tires will be holographically inspected and these readings will be compared to the ultrasonic measurements. To date, YPG has been funded to perform the evaluation and has initiated the TDM procurement action. The program will follow the sequence of events as depicted in Figure 9. Depending on the TDM procurement lead time, either a final or interim report will be prepared in December.

ULTRASONIC TIRE INSPECTION
RRAD PROGRAM

OBJECTIVE –

DETERMINE SAVINGS ATTRIBUTED TO:
REDUCED FAILURES DURING RETREADING
FEWER REJECTED TIRES AFTER RETREADING

STATUS – CURRENT

PWD ISSUED TO RRAD
RRAD FUNDED FOR PROGRAM
HARDWARE TRAINING COMPLETE
PILOT INSPECTION PROGRAM COMPLETE

SCHEDULED ACTIVITY

INITIATE PWD TIRE INSPECTION – JUNE 78
COLLECT AND SUMMARIZE DATA – JUNE THRU SEPT 78
ANALYZE DATA AND COMPILE RESULTS – SEPT THRU OCT 78
COMPLETE FINAL REPORT – DEC 78

FIGURE 8

OBER-RAMSTADT EVALUATION SUMMARY (Figure 10)

There are multiple objectives for the Ober-Ramstadt evaluation. The establishment of TDM ultrasonic accept/reject criteria as well as a possible plan for grading or rating tires to maximize the remaining life expectancy represent two objectives. Determination of the TDM's inspection capability to identify casing quality, that is suitability for retreading, and cost effectiveness are two additional objectives. The final objective is to generate sufficient data to develop a draft TDM usage specification.

Currently, besides setting up the pilot TDM evaluation test plan is being prepared by General American Research Divi-

ULTRASONIC TIRE INSPECTION
YPG PROGRAM

OBJECTIVE –

ESTABLISH DEGREE OF CORRELATION BETWEEN ULTRASONIC AND HOLOGRAPHIC MEASUREMENTS AND REMAINING USEFUL TIRE LIFE

STATUS –

YPG FUNDED TO PERFORM EVALUATION
YPG TDM PROCUREMENT INITIATED

SCHEDULED ACTIVITY –

EVALUATION MEETING FOR PLAN AND TEST INITIATION
DATA COLLECTION
ANALYZE DATA AND COMPILE RESULTS
COMPLETE FINAL REPORT

FIGURE 9

ULTRASONIC TIRE INSPECTION
OBER-RAMSTADT EVALUATION

OBJECTIVES –

ESTABLISH TDM ULTRASONIC ACCEPT/REJECT CRITERIA
DETERMINE TDM EFFECTIVENESS FOR RETREAD QUALITY INSPECTION
COST JUSTIFY ULTRASONIC INSPECTION
DEVELOP TDM USAGE SPECIFICATION

STATUS –

EVALUATION/TEST PLAN BEING PREPARED
SELECTED FIELD USER ORGANIZATION

SCHEDULED ACTIVITY

INITIATE EVALUATION – 3RD QTR 79
COLLECT AND SUMMARIZE DATA – 3RD QTR 79 TO 3RD QTR 80
ESTABLISH ACCEPT/REJECT CRITERIA – 4TH QTR 80
COMPLETE ECONOMIC ANALYSIS – 1ST QTR 81
DRAFT TDM USAGE SPECIFICATION – 2ND QTR 81

FIGURE 10

sion (GARD) and will be evaluated prior to implementation at Ober-Ramstadt. The TDM evaluation plan will include:

a. Identification of all parameters which can affect the TDM readings (i.e., ambient temperature, tire temperature, TDM probe pressure, etc.) during TDM usage for both pre and post retread tire inspection. For each of the parameters identified, a brief discussion of the parameters' affect on TDM measurements will be provided, along with the recommended experimental approach for controlling or eliminating the parameters' influence in determining the degradation reading correlation with tire casing quality or the tires' remaining useful life (i.e., eliminate affect through randomization, specifying parameter range or value, etc.).

b. Identification of what and how the various facets of the retreading process (i.e., casing repairs, buffing texture, retread rubber quality, etc.) might affect the post-retread tire degradation readings and a description of how such readings could be used to assure retread quality.

c. Identification and preparation of the recommended procedures to be followed during pre and post retread inspection with the TDM.

d. Identification of data, which must be recorded for control of the evaluation.

e. Identification of method and procedures for prescribing tire failure mode (i.e., degraded casing, manufacturing defects, road hazards, etc.) for retread tire field failures during the TDM evaluation.

f. Recommendation for TDM hardware support and maintenance during the evaluation.

The other accomplishment to date has been that the Ober-Ramstadt personnel have contacted the Commander of the 37th Transport Division about conducting the field tire life evaluation on the tires o the 37th's vehicles. At this time, it appears that the 37th Transport Division will cooperate and participate in the evaluation. Again, the evaluation is scheduled as shown in Figure 10 with the program culminating with the draft TDM usage specification for ultrasonic inspection of retread tires.

REFERENCES

"Ultrasonic Inspection for Tire Retreadability", I. R. Kraska, Nov 1974

"Water Effects on Tire Maintenance Expenditure Limits", T. A. Mathieson, April 1976

TIRE SEALANTS: FUNCTIONAL REQUIREMENTS; STATE OF THE ART; PROBLEM AREAS; ECONOMICS

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This paper is presented to provide a look at one of the more controversial subjects of tire maintenance—the use of internal liquid coatings for sealing, balancing, and cooling tires with a view to reducing failures and extending service life.

Over the years, there have been numerous attempts at developing tire sealants. These have ranged from combinations of turkey feathers and India rubber, to straw and condensed milk, to some of the more sophisticated polymer chemical combinations. In recent years, a variety of foam materials have been used in various applications with variable success. While these materials are effective in specific applications, the cost and limitations have restricted their use. Some areas of both Canada and the United States impose maximum speed limits on foam filled tires, usually less than 10 mph. Of primary interest to me has been the more versatile materials which, rather than fill the entire air chamber, simply provide various degrees of coatings to the inner surfaces of the tire. A review of past literature, including issued patents, and discussions with almost anyone in the tire industry quickly indicates that there have been some rather unfortunate experiences with these materials. On the other hand, there have been some excellent experiences, with some products.

Basically, past failures can be divided into two major groups, Product and Application.

PRODUCT: There have been many products which simply failed to perform. Some of the bad habits have been:

(a) Freezing
(b) Damage to the tire or rim materials
(c) Deterioration forming rubbery lumps
(d) Failure to seal even minor punctures

APPLICATION: As with any product there are limitations. Unfortunately, some overzealous salesman and/or overanxious customers tend to ignore those limitations and try to use the wrong product for the wrong application. At best the results are disappointing, at worst, disastrous.

As with anything else, a good product in the proper application, with realistic expectations, will perform satisfactorily.

FUNCTIONAL REQUIREMENTS: A puncture sealant has to meet several basic requirements, some of which tend to be incompatible.

1. It must coat the entering, puncturing object and provide an air tight seal. When the puncturing object is thrown out, or otherwise removed, the sealant must flow into or over the aperture and seal the hole.
2. The sealant must stay in place across the full tread, notwithstanding the 160 g's of centrifugal force in the shoulders of a truck tire traveling at 60 mph.
3. It must be stable and able to function over a wide range of ambient temperatures.
4. It must either assist in balancing the tire or have little or no effect on balance.
5. It must be compatible with tire and rim components.
6. It must be easily removeable prior to retreading.
7. It must be easily and economically applied.

This paper will be limited primarily to the use of sealants in truck and earthmover type tires. Passenger and light truck tires present special problems with balance. Low pressure, short radius, high speed tires, are subject to rather extreme deformation in operation. The more viscous fibre based sealants can adversely affect balance in these tires. While this does not necessarily occur in every case the results are inconsistent enough to warrant avoidance of passenger type tires with viscous fibre based materials. There are, however, several low viscosity non-fibrous sealants which have little or no affect on balance which can be successfully used to seal small leaks in passenger and light truck tires. Some of these products do provide excellent protection against slow leaks caused by rubber porosity, rim/bead leaks, and small pinhole punctures.

SEALANT: In attempting to define an effective sealant, it is necessary to define:

1. What types of air leakage are to be stopped?
2. What level of performance is acceptable?

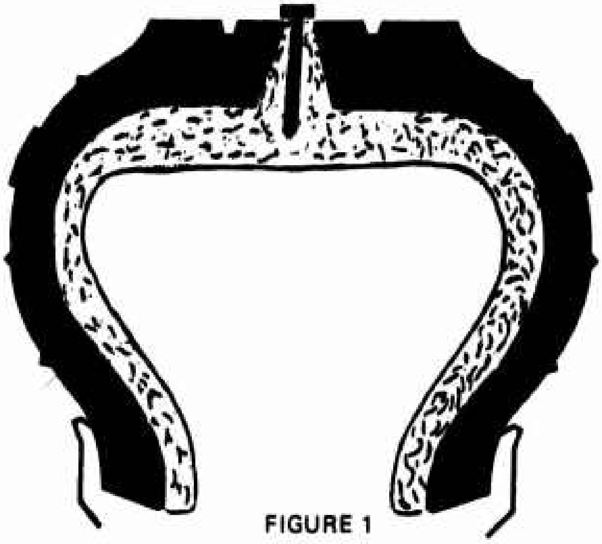


FIGURE 1

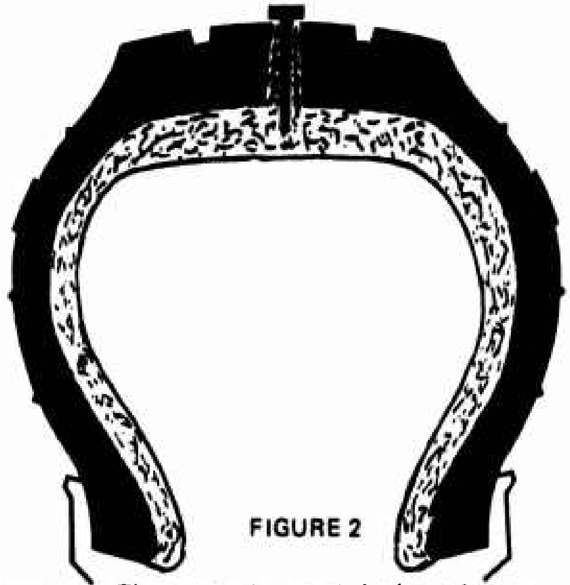


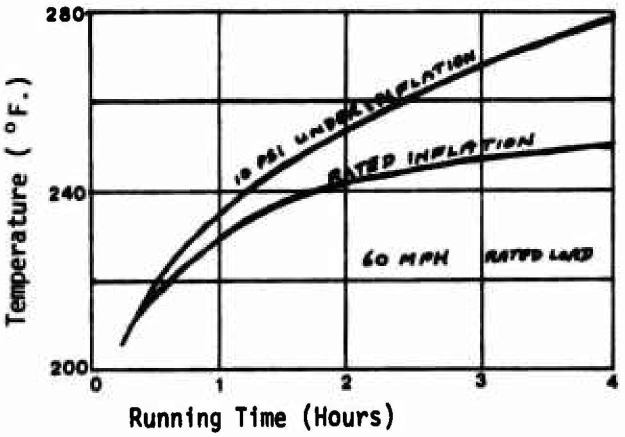
FIGURE 2

Air leakage can come from a variety of sources including:

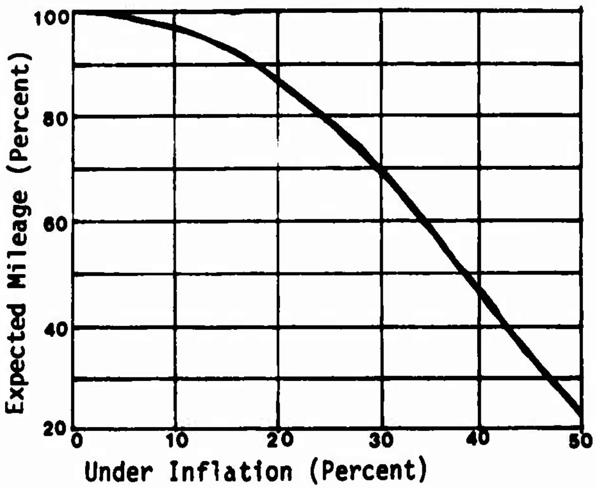
(a) Punctures
(b) Rim/bead interface imperfections
(c) Porous or flawed inner liners or tubes
(d) Rim imperfections, i.e., pinholes at welds.

Acceptable performance level is usually an individual matter, primarily economic in nature. In some operations, a flat tire is only a slight inconvenience and a relatively rare occurrence. These operations are indeed rare. In most operations, a flat tire can mean substantial expense, and in some cases, disaster.

We have developed, with a great deal of help from a large number of companies and organizations a product which performs particularly well in a wide variety of applications. The material is a short fibred mixture in colloidal suspension with anti-freeze, adhesives, lubricants, diluant and corrosion inhibitors, among other ingredients.



TIRE TEMPERATURE



EFFECT OF INFLATION ON MILEAGE

It would appear that for many truck tire operations, the 90 percentile puncturing object is typically represented by a 12 gauge nail (0.100" diameter). As part of our continuing evaluation program, testing was conducted on the product by Smithers Scientific Services, Inc. A copy of their report is included in this paper.

Testing has been directed at achieving 100% sealing of tread area punctures by the 90 percentile object. Our objective was to achieve a 90% reduction in the incidence of flat tires in the average highway operation using tubeless tires.

While the exact mechanics of why this material effectively seals most punctures are theoretical, it would appear that FIG. 1, Fluid carrying fibre and filler enters the puncture as the hole in the rubber spreads under load. An adhesive coats the sides of the hole and the fibre and filler begin to adhere. FIG. 2, the fluid is squeezed out as the tire rolls off the load point depositing the fibre and filler. Repeated rolling, under load, deposits more fibre and filler until a solid plug is formed. This process is repeated when the nail is removed. The tire must roll under load after the puncture to assure proper sealing. Under actual operating conditions, this entire process is almost instantaneous.

One of the most frequent causes of tire failure is underinflation. An underinflated tire runs hotter, wears faster, and is much more subject to being punctured. Maintenance of the specified inflation pressure is vital for full service life.

Rubber is relatively porous. Most tires will lose air over a period of time, some faster than others. We have found that a good tire sealant can reduce or virtually eliminate that porosity and can act as an aid in maintaining the specified inflation pressure. We live in a very imperfect world and even the best manufactured rims and tires are subject to frequent punishment from missed hammer blows and careless handling, etc. Rim and bead leaks are frequent. A good sealant can compensate for many of these problems.

Tread separations, particularly with tubeless retreads, are a major headache which can, in many cases, be avoided. These separations frequently are caused by small holes through the inner liner which are missed in the pre-retread inspection. High pressure air passes through the hole to the new rubber of the tread, FIG. 3. Its escape route cut off, it spreads out between the old casing and the new tread until separation occurs. By effectively sealing these small liner holes, the pressure on the new tread can be reduced so that full service life is achieved without incident. In my opinion, given the frequency and severity of this problem, the use of an effective sealant in tubeless retreads should be mandatory.

If it is found that the sealing characteristics are not as expected, check for:

1. Oily or lubricated puncturing object
2. Lack of sealant in the tire.
3. Sidewall puncture. The rubber continues to work to break the seal.
4. Rips, tears, or cord damage.
5. Stretched rubber, sometimes found in overinflated tubes.
6. Proper tube size for tire.
7. Puncturing object larger than 0.1" diameter.

A question has been raised on the effect of leaving nails in the tire and their possible effect of working to enlarge the hole. We have seen no instance where this problem has, in fact, occurred. We do, however, recommend regular tire inspection and removal of these nails. It is important to keep in perspective the maximum size of hole that a sealant can plug. If indeed the hole were enlarged, the tire would simply go flat long before irreparable damage were done. What seems to actually occur is that the vehicle makes it to its next inspection where service is more easily and economically carried out. Routine in-shop service is invariably less expensive than on-the-road service calls. In the case of a major puncture, the leakage is usually slower, allowing the driver to maintain control of the vehicle for a safe stop.

Three has also been concern about the effect of sealants on steel belted radial tires. Some fears have been raised that moisture could attack the belts causing separation.

To put this into perspective, it must be realized that the majority of punctures are stopped by these belts. That is their primary purpose. These incomplete penetrations can

FIGURE 3

allow outside moisture to reach the belts by capillary action. This outside moisture is usually highly contaminated and has strong corrosive action. The effect of a tire cooling while moist on the outside can aggravate this problem and the moisture can penetrate the rubber sidewalls directly or through vent holes.

A good sealant contains effective corrosion inhibitors for protection of both the rim and steel belts. A complete penetration through the belts to the air chamber allows corrosion inhibiting material to protect the belts from deterioration. In short, a complete penetration is safer.

Concern has been raised that sealants might pass through the inner liner to attack the belts. In the case of severely defective liner this would seem possible. However, a good sealant will form its own liner effectively compensating for the original flawed liner. It is interesting to note the calcium and water ballasting charts produced by manufacturers of steel belted tires.

The puncture sealing capability of a tire sealant will, of course, vary between tube type and tubeless tires. The greatest efficiency is in tubeless tires, for obvious reasons. However, we have had exceptional success with tubetype tires in highway fleet operations. While the material will seal some tube type punctures, we feel that the primary reduction in flat tires has come from the material helping to maintain the correct inflation pressure. A properly inflated tire does not tend to pick up nails etc. as easily as a hotter, underinflated tire. The sealant may be preventing the problem in the first place, rather than correcting it after the fact. Whatever the reason, controlled fleet tests show substantial improvement with the product.

Sealing capability will also vary between highway and the slower Off-road tires. The higher speed highway tires tend to have concentrated protection in the tread surface area, the area most likely to be punctured. We have noted, that a thin moist film is retained on the sidewalls, and in the rim/bead area. When the tire is moving at lower speeds it tends to allow the material to coat these areas chich, of course, can help seal rim/bead leaks and porosity leaks. The much slower moving earthmover tire tends to spread the material more evenly throughout.

BALANCE: Out-of balance highway tires can be costly. These tires bounce and scuff the tread away as they hit the road. This bouncing reduces tread life and can impair driver control. Vibration also causes excessive bearing wear, chassis damage, and dangerous driver fatigue. With conventional lead weight balancing methods, dual tires and wide floatation tires are almost impossible to balance. A liquid sealant of the correct viscosity can hydrodynamically balance highway truck tires for longer tread life.

In any rotating body with an unequal weight distribution, the center of gravity is closer to the heavy side of the body. This holds true in an unbalanced tire assembly. Since the tire will try to rotate about its center of gravity, which is toward the heavy side of the tire, the light side of the tire will travel through a longer distance. Since Centripetal force, $C=MV^2/R$, where M is the Mass at a point, V is the Velocity of the point, and R is the distance from the center of Rotation; therefore, on the light side of the tire the centripetal force is greater. Because of the larger centripetal force on the light side, more fluid will flow to this area. This action returns the center of gravity to the center of the wheel assembly, where it belongs.

The product's ability to remain mobile is vital. This allows it to shift as the tire wears or road and load conditions change. It would appear that the viscosity of the product is an important factor in its ability to act as a balancing agent. If the viscosity is too low, a confused wave action can be set up reducing or eliminating its ability to act as a balancer. If the viscosity is too high, the material could pool in one place after standing for an extended period and be difficult to redistribute within the tire. It is for these reasons that adequate freezing point depression is essential and that product stability is important. In some products there has been a tendency to use some natural or synthetic cross-linking polymer gums which under extended heat conditions have tended to cure and ball up in the tires. This, of course, aids neither balance nor sealing. The use of very long fibre can also aggravate the tendence to ball up. While the viscosity tolerance is relatively wide, it certainly is a consideration.

A curious condition has been noted in assessing the balance capabilities of liquid sealants. As yet we are uncertain as to the reason for this condition. In mechanical spin-balance testing, the tire may or may not show as balanced. In over the road testing, vibration analysis will indicate a consistently balanced condition. The ability of liquid to balance is directly proportional to the quantity installed. In a 10.00 x 20 tire, lead weights are placed approximately 10 inches from the center of the wheel. A liquid in the tire is approximately 20 inches from the center of the wheel. Therefore, half as much liquid weight will do the same job as the lead weights. As the total liquid is widely distributed, only a small part of the liquid actually acts as a balancer. We have found with 10.00 x 20 tires that 32 ounces of sealant can provide balancing the equivalent of 12 to 14 ounces of lead weight. It can be assumed that 6 to 7 ounces of liquid is actually used for balance, or roughly 20% of the installed quantity. Increasing the installed quantity helps, within limits. For a properly mounted, reasonable quality 10.00 x 20 tire, 32 to 40 ounces of sealant should normally be adequate to achieve proper balancing. In tubeless tires with exceptionally heavy liner ribbing, increased quantities may be needed to allow the material to flow over the ribbing. With tube type tires, care should be taken in mounting the tube in the tire. Folds or creases can act as a dam, preventing the free flow of the liquid. This occasionally happens where an oversized or stretched tube is used.

While many fleet operations balance the steering axle tires, most do not even try to balance either the drives or the trailer tires. This results in a great waste of potential service life on the unbalanced tires. While balancing these drive and trailer tires with lead weights on the rims is extremely difficult, if not almost impossible, liquid balancing provides an inexpensive, quick and easy solution to the problem. Because the liquid automatically seats itself in actual operation, the tires can run consistently balanced for extended tread life.

On the initial installation, it will take a few miles of driving to distribute the fluid within the tire. Subsequent runs should balance within a few hundred yards. Liquid balancing can be used in truck and bus tires 9.00 x 20 and larger. We have also been successful with the smaller heavy duty tires used on auto carrier trailers which run at substantially higher inflation pressures than passenger and light truck tires.

It is important to recognize that not all vibration problems are tire balance related. Where the problem is actually a tire balance problem, a liquid balancer will normally be the solution.

COOLS: Internal liquids can have a cooling effect on the tire. It must be noted that when using a liquid coolant, the contained air temperature may or may not be lowered. Contained air temperature is just that—a measurement of the temperature of the air within the tire. Our concern is with the temperature of specific locations within the tire itself. Because of the variations of internal and external friction on various parts of the tire, and since rubber is a relatively poor conductor of heat, there are substantial differences in temperature at different points within the tire. An internal liquid coating of a good heat conducting material, such as a glycol, can act as a thermal conductor, transferring heat from areas of higher temperature to areas of lower temperature. Ideally, this thermal transfer will keep the temperature of the hot spots below the critical level at which the tire will fail. Thermal conductivity varies with the properties of the liquid, the thickness of the coating, and the extent of the coating. The effect of thermal conductivity tends to be greater in earthmover type tires because of the larger areas of the side wall that are coated. While a slow moving tire tends to be more evenly coated throughout, the high centripital forces generated by highway vehicles tend to concentrate the bulk of the material in the tread area.

A secondary, and perhaps more important, cooling effect is obtained through correct inflation pressure maintenance. An underinflated tire tends to operate hotter. Increased internal flexing heats the rubber making it much more subject to wear.

The use of a good sealant assists in pressure maintenance which in actual operations means that the tires run cooler than the normally underinflated tires.

As discussed earlier, it is important that the liquid be easily removeable prior to retreading. Water soluble materials are ideal for facilitating removal from a puncture area which must be repaired.

Ease of installation is also important. The majority of available sealants are injected through the valve stem after the valve core has been removed. Hand pumps capable of working against the tire's internal air pressure are available and normal installation in a truck tire can usually be accomplished in less than five minutes without removing the tire from the vehicle or deflating the tire completely.

QUANTITY CALCULATION: The quantity of sealant required will depend somewhat on size of the puncture to be sealed, the size of the tire, and the type of operation in which the tire is to be used. If it can be assumed that a sealant layer of 0.050" would be adequate to seal the more normal punctures, then the quantity needed can easily be computed based upon known tire dimensions. Typically, a 10.00R20 steel radial, load range G truck tire has a measured O.D. of 41.50" and a toe-to-toe internal perimeter of 26.9" when mounted on a 7.5" wide rim. The tire measures 10.7" in width at its widest point and has a tread radius of approximately 20.00".

The necessary quantity of sealant required can then be calculated as follows:

$$TSV = (BB) \quad (CIMM) \quad (0.050)$$

Theoretical Sealant Volume = Bead toe-to-Bead toe measurement x Circumferential Internal Mean Measurement x 0.050"

where Circumferential Internal Mean Measurement = O.D. – 2(½ section height)

Therefore $CIMM = 41.5 - \frac{(10.75)}{2}\ 3.1417 = 96.6$

$$TSV = (96.6)\ (26.9)\ (0.050)$$

$$TSV = 129.94 \text{ cubic inches}$$

Knowing that 1.805 cubic inches =

then

$$\frac{129.94}{1.805} = 71.96 \text{ oz.}$$

$$TSV = 71.96 \text{ oz.}$$

Unfortunately, in highway service the sealant material will not stay along the sidewalls due to the action of centrifugal force as the tire rolls. Therefore, the calculation should only direct itself to that area of the tread which is more likely to be subjected to punctures. In this instance, an 11" width should be used instead of the bead toe-to-bead toe measurement of 26.9" (Tread width of 8.0" + 1.5" each shoulder + 11")

Recomputing we obtain:

$$TSV = 96.6 \times 11 \times .050 = 53.1 \text{ cubic inches}$$
$$TSV = 52.1/1.805 = 29.4 \text{ oz.}$$
$$TSV = 29.4 \text{ oz.}$$

Therefore, 29.4 oz. of sealant would theoretically seal adequately.

We have theorized that a sealant layer of 0.050" in thickness will be adequate within the performance aspects of the tire and the environment in which a tire operates. Based upon many variables, actual thickness of a sealant material may vary to almost three times the 0.050" suggested.

Under actual testing, it was determined that the best results were obtained at 40 ounces of sealant in an 11 R 22.5 tire. Recomputing, this would place the sealant thickness at about 0.07".

An alternate and simplified approximation of the desired quantity can be roughly calculated as follows:

Highway Operations – Quantity in Ounces = 0.109 (A(A+B))

Where A = Section Width

B = Rim Diameter

e.g. 11 - 22.5

0.109 x 11 (11 + 22.5) = 40 ounces

OFF-THE-ROAD OPERATIONS

In Off-The-Road Tires, centrifugal force tends to be much less a factor, and the sealant tends to spread out and more evenly coat the sidewalls. While this has obvious benefits in sealing sidewall leaks and rim/bead leaks, it does deprive the inner tread surface area of the liner of adequate protection. To provide this protection, larger quantities of sealant are needed. It is for these reasons that we recommend at least doubling the quantities recommended for a highway service tire of the equivalent size. Converting the above rough formula to earthmover type tires etc. the O.T.R. formula would be:

0.22 (A (A+B) = Quantity in Ounces

e.g. 20.5 - 25

0.22 x 20.5 x (20.5 + 25) = 205 Ounces

As balance is normally not a factor in [illegible] are no minimum size restrictions as in the case of highway service tires. However, as sealing capability is normally of the greatest concern, it is best to restrict a sealant's O.T.R. use to tubeless tires.

While the performance of a sealant will vary greatly depending on type of operation and the standards of tire maintenance in that operation, the results are often difficult to believe. In some operations, flat tires are virtually eliminated. In others, the incidence of flat tires is reduced to an acceptable level. Operations using tubeless retreaded tires have reported virtual elimination of separation failures. In testing by Smithers Scientific Services, 11 R 22.5 tires with eight 0.100" diameter nail holes in each tire successfully completed the Federal Motor Vehicle Safety Standard 119 endurance requirements. There is no question as to what would have happened to those tires without a sealant installed. Many tires which would have been scrapped because of defective liners have achieved full normal service life. In highway service operations, service life extension has ranged from 16% to over 40%.

There are many benefits to the proper use of sealants in many applications. These products are not meant to be a substitute for a good maintenance program. They are a valuable aid to that program. However, I must admit that our results are best where the maintenance program is poorest. The need for good sealants has been recognized by several of the tire manufacturers. Some currently use our product to help improve competitive performance. Some use it to help correct minor manufacturing problems, such as liner flaws. Some companies, such as Michelin, are developing their own formulations. I was rather amused to note the issuance of a sealant patent to Michelin in Britain.

Essentially, tire sealants can be an inexpensive problem. It is a simple fact that a properly inflated, balanced, cool running tire lasts longer and is less subject to failure. A good sealant can help achieve that ideal and allow the operator to get full value from his tire investment.

	FIBRE BASED Flat Guard*	NON-FIBROUS Micro-Seal*	FOAM
Seals Punctures (0.10" Dia.)	YES	NO	YES
Seals Porosity, Rim/Bead leaks	YES	YES	N/A
Balancing	YES	NO	NO
Cooling	YES	YES	NO
Truck Tubeless (Highway)	YES	YES	NO
Truck Tube Type (Highway)	YES	YES	N/A
O.T.R. Tubeless	YES	YES	YES
O.T.R. Tube Type	NO	YES	N/A
Passenger & Light Truck	NO	YES	NO
Legal Speed Limits Over 50 mph	YES	YES	NO

*Flat Guard and Micro-Seal are Trade Marks of Ti'Seco Ltd.

Care must be taken to assure that the selected commercial product has the required performance characteristics and that it is used in the proper application.

Because of the wide variety of applications, controlled testing for suitability is important.

CORROSION CONTROL

Flat Guard has undergone the most extensive corrosion control testing at the University of Western Ontario Engineering Faculty, Tire Manufacturers, and in our own facilities.

PRIMARY PROCEDURE

The numerical values of the corrosion rate were determined by linear polarization technique.

APPARATUS

Wenking Potentiostat
300-400 Ml. Flat Guard Mix
Graphite Counter Electrode
Calomel Reference Electrode
Provision for stirring and heating

Polarization resistance determinations were made with 2 and 4 mV polarizations. In the calculations a factor of 0.026 was used whether or not the electrode was active. Several full polarizations were measured.

Eight coupon specimens were partially immersed in Flat Guard mixes in loosely sealed containers. The containers were at room temperature and a few drops of water added as required to keep the mix wet. These specimens were used to confirm the polarization resistance measurements and to test for water line corrosion.

SUMMARY OF RESULTS

		Corrosion Rate IPY
1. STEEL	26 C (79F)	Passive, Specimen Shiny on Removal
	80 C (175F)	Passive, Specimen Shiny on Removal
2. BRASS	26 C (79F)	0.001"/Year
	103 C (243F)	0.007"/Year
3. ALUMINUM	26 C (79F)	Less Than .001"/Year
(6061-T6)	80 C (175F)	0.002"/Year

The fact that Aluminum reacts slightly is beneficial in that it makes the alloy less susceptable to other forms of local attack.

Attempts to induce pitting corrosion and stress corrosion with Flat Guard were unsuccessful.

Flat Guard will not damage the materials used in tires or rims.

REFERENCES

1. "TECHNICAL AND LABORATORY EVALUATION OF TI'SECO FLAT GUARD TIRE SEALANT", Project 3010-7-18, D.E. Williams, Smithers Scientific Services, In. Sept., 1977.

2. "IMPROVEMENTS IN PNEUMATIC TIRES". Patent Specification 1 496 498, British Patent Office, granted to Michelin et Cie (Compagnie General des Establissements Michelin.

3. United States Patent Office, PATENTS #:

587,982	1,062,525	1,233,753
598,324	1,117,526	1,383,572
599,115	1,690,051	1,467,065
661,124	2,120,379	1,561,332
715,784	2,141,959	1,896,611
825,930	2,286,963	2,003,112
836,569	3,881,943	2,355,977
892,521	1,128,282	2,357,650
981,429	1,143,152	3,676,381

4. "DO YOU UNDERSTAND GALVANIC CORROSION?", C.W. Hawk Jr., Chemical Engineering, June 6, 1977.

5. "HOW CORROSION THEORY RELATES TO COATINGS – PART 11", D.M. Berger, Chemical Engineering, Aug. 29, 1977.

6. "POWER CONSUMPTION OF TIRES RELATED TO HOW THEY ARE USED", W.K. Klamp, Conference Proceedings, Tire Rolling Losses and Fuel Economy – An R & D Workshop, Oct. 18-20, 1977, Transportation System Center, Cambridge, MA.

7. "WATER EFFECTS ON TIRE RELIABILITY", L. Ash and R. Johnson, Second Symposium on Nondestructive Testing of Tires, Oct. 1-3, 1974, Atlanta, Georgia. Pub by Army Materials and Mechanics Research Center, Watertown, MA.

QUESTIONS & ANSWERS

Q: Speaking as a hostile member of the audience, for twelve years I've been with Firestone. For twelve years one of my responsibilities has been tire sealants and everyone comes around and gives the same pitch as you do. They seal the tire. We run the tires on test and we find sometimes they seal, sometimes they don't. We find with tire sealants we have comments like OK they run in testing

TRANSPORT FLEET #1

Test run on 6 new White "Road Boss" tractors for highway transport between Toronto, North Bay, and Timmins. The units travelled on both flat divided highways and high crown roads. 30 tube type 10.00X20 tires on Units#6521, 6522, and 6527 were treated with Flat Guard. 30 tube type 10.00X20 tires on Units #6511, 6512, and 6513 were not treated and were used as a control group. In addition, some trailer units were treated and compared to other untreated trailers.

TRACTORS TREATED WITH FLAT GUARD
30 tires run 1,897,440 tire miles ----- 2 FLAT TIRES (1 flat caused by valve cap left between tire and tube)

TRACTORS UNTREATED CONTROL GROUP
30 tires run 2,481,210 tire miles ---- 13 FLAT TIRES

TREATED tires averaged 948,720 tire miles per flat.(6.7% of tires had flats)

UNTREATED tires averaged 190,862 tire miles per flat.(43.3% of tires had flats)

THEREFORE: 80% FEWER FLATS WITH FLAT GUARD. (adjusted mileage)

TRAILERS
TREATED with Flat Guard ---- 34 tires ---- 1 FLAT TIRE.(2.9% had flats)
UNTREATED CONTROL ---------- 84 tires ---- 22 FLAT TIRES (26.2% had flats)

THEREFORE: 88.8% FEWER FLATS WITH FLAT GUARD

LONGER TERM TESTING INDICATED AN INCREASE IN TREAD SERVICE LIFE OF OVER 20%

ON THE TREATED TIRES.

COST / BENEFIT RELATIONSHIP IN THIS FLEET

ASSUME:
Tractor @ 10 tires + trailer @ 8 tires = 18 tires / tractor-trailer unit.
Tire Cost @ $150 / tire
Balancing Steering Axle with lead weights on Untreated unit @ $20.
Flat Guard Treatment Cost @ $7.00 / tire = $126 / tractor-trailer unit.

Downtime Cost per Flat	$100	$400 (Industry Average)
TREATED UNIT		
Tractor 2 flats/30 tires X 10 tires	$ 67	$268
Trailer 1 flat/34 tires X 8 tires	24	96
Flat Guard treatment cost $7 X 18 tires	126	126
SUB-TOTAL (A)	$217	$490
UNTREATED UNIT		
Tractor 13 flats/30 tires X 10 tires	$430	$1720
Trailer 22 flats/84 tires X 8 tires	210	840
Balancing steering axle with lead weights	20	20
SUB-TOTAL (B)	$660	$2580
DOWNTIME COST/BENEFIT WITH FLAT GUARD (B - A)	$443	$2090
Value of 20% increased tread service life on treated unit.($150 X 20% X 18 tires)	540	540
NET SAVINGS ON FLAT GUARD TREATED UNIT	$983	$2630
NET RETURN ON INVESTMENT AFTER COST	780%	2087%
Overall average net savings per tire per full tractor-trailer unit	$54.61	$146.11

FLAT GUARD

PERFORMANCE NET BENEFIT PER 100 TIRES

GIVEN: 11-22.5 TIRE PRICE @ \$150.00
DOWNTIME = \$100.00/ FLAT
FLAT GUARD COST = \$ 8.75/ TIRE 11-22.5

o/o INCREASED TREAD SERVICE LIFE

NUMBER OF FLATS PREVENTED / 100 TIRES	0	5	10	15	20	25	30	35	40	45	50
0	-675	75	825	1575	2325	3075	3825	4575	5325	6075	6825
2	-475	275	1025	1775	2525	3275	4025	4775	5525	6275	7025
4	-275	475	1225	1975	2725	3475	4225	4975	5725	6475	7225
6	-75	675	1425	2175	2925	3675	4425	5175	5925	6675	7425
8	125	875	1625	2375	3125	3875	4625	5375	6125	6875	7625
10	325	1075	1825	2575	3325	4075	4825	5575	6325	7075	7825
15	825	1575	2325	3075	3825	4575	5325	6075	6825	7575	8325
20	1325	2075	2825	3575	4325	5075	5825	6575	7325	8075	8825
25	1825	2575	3325	4075	4825	5575	6325	7075	7825	8575	9325
30	2325	3075	3825	4575	5325	6075	6825	7575	8325	9075	9825
35	2825	3575	4325	5075	5825	6575	7325	8075	8825	9575	10325
40	3325	4075	4825	5575	6325	7075	7825	8575	9325	10075	10825
45	3825	4575	5325	6075	6825	7575	8325	9075	9825	10575	11325
50	4325	5075	5825	6575	7325	8075	8825	9575	10325	11075	11825

EG.: IF 35 FLATS PREVENTED AND 30% TREAD SERVICE LIFE INCREASE THE NET SAVING WOULD BE \$7,325.00 PER 100 TIRES.

laboratories and these tires would assuredly fail if they did not have the sealants in them. However, I've had many, many examples where tires have run perfectly well with nails in them and when they've been removed, the retreaders will find five nails in the tire was obviously holding air. I am really wondering what is different about your sealant? I am very interested in sealants and have spent so much of the company's money and it bothers me when someone gets up and says they have developed one that works. Frankly, I've wasted a hell of a lot of my company's money and my conscience bothers me a lot. I'm willing to test someone else's but I'd like to know what is different about it.

A: I hate to get a hostile member of the audience excited but Firestone approved our product; they tested it several years ago. Quite a number of their branch operations throughout Canada have been using the product for the last four years.

Q: Firestone in Canada?

A: Firestone in Akron tested the product and accepted it as nonharmful to the tires and to the rims. As far as the other testing that you've done down there, I really don't know.

Q: That testing would have been accomplished in my department, and I don't know of any tests.

A: You'd better talk to John Byers.

Q: OK, I'll talk to John Byers.

A: I also have a copy of the letter from John on the product.

Q: You said that Michelin has a patent on it.

A: Yes, they are using the ingredients in our formula.

Q: Why don't you have a patent on your formula?

A: Because we withdrew our patent application. The patent was granted, and we withdrew it just prior to publication. It's not exactly the same formula, but one of the things we've recognized in the chemical industry is that it is one of the worst industries for patent piracy. We prefer the trade secret route. So far we've had four different tire companies and other companies trying to break our formula and they haven't been able to do it yet. If somebody can do it, they're welcome to it.

CHAPTER IV

WORKING GROUP REPORTS

Charles P. Merhib, Moderator

ULTRASONIC WORKING GROUP REPORT

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The meeting of the Ultrasonic Working Group started with a review of the ultrasonic tire testing methods, who was doing what in development and the use of the various techniques. John Burche reported on Bandag's efforts in developing the air couple sonic system. Irving Kraska reported on the ultrasonic immersion system and Dick Johnson fielded questions on the GARD TDM. Several inquiries were made about the future plans for the use of the DOT pulse-echo system. Unfortunately, there was no DOT representative present to field these inquiries. We discussed at length the tire depradation monitor, its use in retreading, quality assurance, and new tire development. Various participants described their experience with the TDM. Mr. Clerger of Armstrong Rubber described their interest in monitoring their new tires and Dick Baumgardner of Firestone talked about his experiences with the unit. The general opinion seemed to be that the use of the contact ultrasonic pulse-echo system seems to be a reality for degradation and QC purposes. The successful uses of the TDM in the retread shops is somewhat dependent on the interests of the operator and knowledge and use of the tires. This is practical for the independent retreader but more difficult for the tire manufacturers' retread plants. More in-plant experience needs to be gained in manufacturers' retread shops, in human factors, and job motivation area. The use of contact pulse-echo ultrasonics in new tire development seems to be practical and its full potential has not yet been realized. Steel-belted radials, at the retread plant level, separations are still a problem. This problem may be a good application for the thru transmission or the 360^{o} scanning pulse-echo systems. Currently, no such systems are available, however, several manufacturers are working on them. Truck tires, the use of pulse-echo for nylon and steel: the capability seems to be there and in fact it is in use at the retread level, and since military tires resemble commercial truck tires, the use of ultrasonics seems very practical and is currently being pursued by the Army. The use of ultrasonics for aircraft tires has been shown feasible, but not enough work has been done to prove that it is practical. If degradation is found to be practical, for aircraft tires, it could be very cost effective and could be used as a day-to-day routine on vehicle inspection procedure. Further research in ultrasonics should be pursued. Ultrasonics is one of the few NDT methods shown to be fast enough for production use. Again, it seems to be the consensus of all the working groups that a very important point brought out was the encouragement of more cooperation and exchange of information both research and use between the tire manufacturers and equipment manufacturers working in the ultrasonic field. More important are the results in overall use is needed.

Q: Can NDT be used for on-the-vehicle inspection? Has there been a history of somebody using it?
A: Yes, we've used it both on military applications and the commercial retread plant. We actually monitored some of the tire testing that we've done out at the Yuma Proving Grounds with actual on-vehicle inspection. For example, we're running the 151 jeep and prior to the driver going out, we inspected all four tires. We told him to be careful, since one was defective and indeed two hours later he came back with a flat tire. The tire had actually failed. We have run both the 2½ ton truck and a jeep in the Chicago area. We piggybacked some other tests. They had some diagnostic equipment on them for some 20,000 odd miles and we did our on vehicle inspection every 2,000 miles. In addition, we did go to a retread plant, a commercial retreader, who was experimenting with retreading. What he wanted to do was take just the whole wheel off and retread it without demounting it. Just drive the truck in, remove

the wheel from the vehicle, retread it, and stick it back on. We did do our tire test on the vehicle but it was done before demounting the tire.

Q: Is there a very significant difference between the signal readout?

A: Actually what happens is that you get better reflectivity off the ply layers because of the inflation pressures in the tire.

Q: How long does it take to run the test?

A: Tests like this take about thirty seconds as long as you're not documenting anything. Once you start documenting then it takes a lot longer, but we just simply make the inspection.

HOLOGRAPHY WORKING GROUP REPORT

R. M. Grant
Industrial Holographics, Inc.
Auburn Heights, MI

The Holography Committee consisted of over thirty people, and I think a brief comment should be made before trying to summarize the opinion of that committee. In view of the recent DC-10 accident which occurred in Los Angeles and which was caused by tire failure, many of the people on the committee who are in the field of tire manufacture and tire testing had that particular accident on their minds constantly during the last few weeks. Therefore, much of our discussions centered around what the basic concept/reject criteria are in the aircraft tire industry.

Carroll Shaver, from Air Treads, served as a focal part of that conversation and did a very excellent job of summarizing for us the commercial testing which is presently being done in industry by and large on commercial aircraft tires. Approximately three quarters of the time was then spent on the concerns regarding the reliability of the accept/reject criteria that is presently being used in commercial testing, and an evaluation of whether that criteria was realistic.

In the past, the criteria, had been typically one half inch separation diameter, (actually ½ ± ¼). Experience has shown over the recent past that acceptance or rejection of a tire due to the existence of a ½ inch or (smaller) separation is much too tight a criteria. Recent commercial airline tires are being accepted or rejected on a criteria of allowing separations up to one inch to pass in the central crown region of the tire; or rejection for any size separation when the carcass is extremely weak and fatigued. In other words, the newer accept/reject criteria is ½ ± ½) inch, depending upon the strength of the carcass.

One commercial carrier experienced approximately forty failures in the last year before using holography. Then, using holography and the above described more liberal accept/reject criteria which was instituted, that airline experienced no other tire failures for over a year as a result of separation.

A second airline company has experienced approximately a dozen failures in a single year prior to requiring holography. They had established a ½ inch diameter separation accept/reject criteria which was probably a bit too severe. With holography, that accept/reject criteria was liberalized slightly, and evidence now is that the airline did not experience any additional failures as a result of the new criteria.

So again, most of the committee discussion centered around the realism of the accept/reject criteria and the liberalization from (½ ± ¼) to (½ ± ½).

The committee then moved on to discuss a feeling of disappointment that so few of the rubber companies had taken part in, and actively participated in any previous sessions. One of the suggestions which came out of our discussion is that a possible alternative to the procedure which we have used in the past four symposia, would be to allow individuals to present their views without having them published.

STANDARDS WORKING GROUP REPORT

R. Yeager, Chairman
Goodyear Tire & Rubber Co.
1144 E. Market Street
Akron, Ohio

Good morning, Ladies and Gentlemen. I'd like to first thank Paul Vogel for his time spent in preparing and conducting this Symposium and also the assistance given by Mr. Merhib and Mr. McConnell. The standards working group met for nearly two hours yesterday. We had nine participants in the field of tire NDI specialists representing four of the major rubber companies, the Army, the Navy, FAA, and independents. I think this was a milestone since it was the first committee meeting to discuss standards here. It was generally concluded that the field of standards is a very complex subject and no overnight breakthroughs are going to happen. The first order of business is an attempt to set goals for this committee. These can be in the area of providing a sample block to evaluate X-ray, ultrasonics, and holography. These three were considered plus any new development type of nondestructive technique that may come up. The sample block could be a step block with built-in separations and this could be used within the industry to coordinate a standard type of testing and to give the suppliers a suitable sample to initially evaluate their products. From all of this will probably evolve a glossary of terms and additional terms which could be applied at any later date. I plan on working with the participants in order to arrive at a mutually agreeable set of goals, glossary of terms, and finally establishing a test standard block. These could then be presented at a later time. I would recommend a national meeting on a less frequent basis and then probably have a committee meeting whenever anything of interest or value is established.

Q: Why a block instead of a tire, for instance?
A: I think a block is easier to use. It's a first step. For example, if you use a block, you could have a series of them, not necessarily just one. You could have a series of blocks with different types of separations built into them or different types of defects or anomalies whatever we agree on. You could set this up very quickly and run tests on it. It would give you a working knowledge. Within the industry, for example, you could sent it from plant to plant, among the nondestructive testing pieces of equipment. Let them try it out. It would be easier to handle. A tire I think is a long step because you are going to have to agree on bringing a mold in and the type of tire, whether it be a passenger, truck, airplane, military or retread. I just think right now at this time a tire would be very difficult to agree on. The type of tire would be a very long range program to come up with a standard. It would certainly be a worthwhile goal.

QUALIFICATION WORKING GROUP REPORT

G. McConnell
Naval Air Development Center
Warminster, PA

My thanks to Air Treads, Piedmont Airlines, BF Goodrich, and the Naval Air Rework Facility at North Island, for participating in the Qualification Working Group. We unfortunately didn't have a good cross section of the tire industry or rubber industry. Our representation was primarily aircraft-related people.

Since most nondestructive inspection processing does not produce subjective evidence of the product quality, the individual inspectors' knowledge and skill combine to establish the sensitivity and reliability of the inspection process. Therefore, most commercial organizations, all DoD departments and agencies, and all DoD contractors have mandatory standards which establish the minimum requirements for training, qualifying, examining, and certifying nondestructive inspection personnel. Our working group discussed existing standards and the most prominent of which are the American Society of Nondestructive Testing recommended practice, SNT-TCIA, and MIL Standard 410D. We talked about equipment qualification and the need for uniformity among the many facilities performing nondestructive tire inspection. The operation of nondestructive inspection effort is often restricted for the following reasons. The speciality is just too new and not properly understood by supervision and management. My experience shows that often direct supervision has no real appreciation for the methods, they are not trained, and management is further removed and is worse in that respect. Inspectors often perform the nondestructive work as a collateral duty and this tends to neutralize their proficiency. Many organizations have no formal inspector training programs. I have had a document shown to me from many of the tire companies so the retreaders that do military work have a document for standard qualification but, I haven't seen any from the commercial tire companies. The final thing is that quality assurance people often have no real control of nondestructive processing. During our discussion, many cases have been cited to demonstrate improved reliability because of nondestructive inspection but we also recognize that we do not always have the desired capability-uniformity among facilities. For instance, one organization may have a half a dozen or a dozen different nondestructive and test facilities and they have personal preferences. Not all of them but some organizations have personal preferences for the quality of work that comes from one or two or several of their facilities. The conclusions and recommendations are that qualification and certification standards are necessary. That we should use common qualification certification standards for commercial and military aircraft tires. Separate qualification certification should be required for each inspection method, and MIL Standard 410D should be updated to include holography.

In conclusion, we express our thanks to Paul Vogel; the Army Materials and Mechanics Research Center, the host activity; for conducting this Symposium. We would like to ask the Army to consider a request. I think most of you are familiar with a report that Paul wrote that was published in Rubber Age about five years ago. Now with four symposia behind us and five years of progress and new techniques, we feel an update of Paul's report would be of great value to the entire rubber community. Mr. Vogel is knowledgeable in these fields, and his tact and respect for industrial competence gives him a unique qualification and ability to gather together the most information into an entire NDI report. So since we are deeply concerned with equipment and techniques, we list as an Army need an updated state-of-the-art survey; and we would like Paul to do this if possible. We would like to see as much statistical information as is available to assist in understanding the capabilities of the various inspection methods.

Thank you.

X-RAY WORKING GROUP REPORT

D. T. Greene, Chairman
Imagex, Inc.
Mentor, Ohio

The following recommendations are respectfully submitted:

1.0 The need for standards for evaluating performance of X-ray equipment is recognized.

1.1 Suggested method is to have a group of interested and knowledgeable people from the tire industry, the X-ray manufacturers, concerned Government agencies, with participation by a member of a suitable existing standards organization, hold two or more one-day meetings at monthly intervals to formulate the type of standards required to properly judge performance of X-ray equipment.

1.2 Any necessary funding for preparation of standard samples as decided by this group is unlikely to be provided solely, if at all, by the tire and X-ray manufacturers, and should preferably come from interested federal agencies.

1.3 It is not intended to imply that any standards will be set up, or judgements made, about the quality of finished product as a result of the above, but rather that the results be confined to the evaluation solely of the X-ray testing equipment itself.

2.0 We recognize a change in X-ray technology which will permit very rapid examination of certain structural features of tires without the use of human operators at a much lower cost per tire, and which provides outputs in digital form. We suggest that the impact of the new technology be recognized and that DoD inform itself on this subject.

3.0 We believe that there would be advantages in a combined program that would simultaneously apply the several NDI systems, such as X-ray, force variation, ultrasonics and holography, to study how they complement each other. A test series where a large number of tires is analyzed by all of these methods, taking into account the recent availability of modern X-ray and holographic equipment which can provide digital rather than subjective data, should provide valuable correlation information which seems lacking at present. We strongly feel that any single test method is most unlikely to be a panacea, and that some combination of methods is the proper route for the future. A test program as outlined, using only the most modern equipment available, should point out the proper future direction.

CHAPTER V

PANEL DISCUSSION

Mr. Kyriakides: I would like to make some comments to the participants involved. I would say at this time it is very important that the proceedings consider the problems of the consumer and the big problem to the consumer is the problem of radial tires. You are aware that now, over 80% of new cars are equipped with radial tires, and since this change we are taking is very, very fast. In a very short time, we will face a real problem. And the real problem in radial tires is belt edge separation. This type of failure in the radial tires presents a belt edge separation, and this separation is due to curing of compound. The radial belt edge due to flexing will start very, very slow tearing and this type of tearing will extend in time and is to be in direct proportion to the age of the compound. The method just to detect and to establish a relationship between this propagation of tearing or separation in the radial belt will be extremely important. We performed some tests, and I was a little disappointed with that I didn't hear it now.... Hear about infrared method which should also be considered official. All these methods presented yesterday, they were very important, very interesting, very valid results but at the same time we got some very interesting results on infrared methods also at Monsanto. The problem on infrared is to establish a warm-up period which could be very short in order to warm-up the tire and after this we got very promising results. This doesn't mean it will be the method of the future, but I would say that this method should be considered official also as a nondestructive test which seems to be promising also besides programming, holographic, ultrasonic and X-ray technique.

Mr. Vogel: We have a partial answer to your question. We are very active in infrared at the Army Materials and Mechanics Research Center. I wonder, you have explored with Monsanto an active infrared test where you inject heat temporarily and then look for the flaw in the cooling process. We have just finished a preliminary study with infrared for the Navy on a part that resembles a massive 5-steel ply tire. We are developing a new instrument that will hopefully do a very rapid macro scan of that so that we can then get down and do the micro with a smaller infrared instrument. These are two instruments we have under development, one is a pyroelectric vidicon which will do away with the cooling problem involved in the present infrared techniques and the other one is a single-line scanner. We aimed initially at looking at the integrity of the long spars, the rotors, on helicopters. It would also be ideal for looking at the aircraft wings for water content, for example, which the airline people say is a tremendous problem. When they are carrying tons of water, that's tons of fuel that they are not carrying. There, this single line scanner would be of advantage too. We would like to hear more of your problem and your interest in infrared and possibly pursue this as an Army need if you could maybe boil the problem down to a few paragraphs and drop us a note. We may have the equipment just down the road a little bit that could answer your need.

Mr. Shaver: In regard to what's been said about future symposiums, and participation of many papers and so forth, we have all kinds of problems, individually and company, not the least of which the gentlemen of Goodyear pointed out that we have a lot of different hats to wear. Some of our people have to wear so many that they've worn their hair off. In the Atlanta symposium I presented a paper on what we were doing in holography and when the next symposium happened in Akron I told myself well we're not doing anything new, so it will just be a rehash of the old paper. When Paul sent out the deal on this one, the same thinking process went through my mind. But I think really that what I need to do is to plead guilty to complacency and plead guilty to just wanting to come along and take the easy route out and listen to what other people have to say and present. I plead guilty to not having a full realization that everybody that comes to these things has some kind of obligation to put a little into the pot, rather than always reach in and take something out. Pretty soon the cookie jar runs dry. There is a slight indication made that the interest in these things is waning and it really shouldn't be but we are all trying to come and take something out of the cookie jar and not put anything back in.

Perhaps it is incorrect to think that we're not doing anything new at Air Tread, so what is there for you to talk about? Yet, it seems that even people like Dr. Kruger in Germany on truck tires is interested in what we are doing in airplane tires. So maybe we're not doing so many *new* things but we're doing *more* and more of it. I think it would be of some interest for people to know to what gradually growing extent we're getting into nondestructive testing. We operate machines and tire plants on a continuing day-in-day-out production basis. And by the next symposium there's just no telling to what deeper extent we will be into nondestructive testing. I even wondered if we should try to broaden the scope a little bit. And instead of just tires, go tires and wheels. But then I recognize the fact that we are not just talking airplane tires. We at Air Treads are at the present time being forced into doing such interesting NDI work on wheels in that we are having to make our own machines. We have a machine right now about 90% complete that will do what the Dr. Foster system has done so well for SAS in automated scanning of the tube wheel-well

The thing that we're doing different is instead of having to hand-scan that very important place which is the bead seal radius, our machine is going to turn that corner and come on up the wheel flange. That is just something that we must do and we are doing it in aircraft wheel NDI. There is enough interest in what we have so far that we have some airlines extremely interested in having us make this. But I think I can assure you that when the next symposium is held, and the invitation for papers comes up, Paul, I will look at it in a new light and not try to be as lazy as I've been in the past and I will see if I can put a cookie back into the jar.

Comment: In casual conversation with major tire manufacturer employees, they really are under pressure not to come to this environment and they have even had subtle threats of job loss if they violate certain rules set up by management. So I think we're talking to the wrong people. There is upper management putting planks on this and how do you get to them. Everyone appears to know that there is a threat.

Mr. Merhib: Yes, that is a basic problem. I don't know how you reach those people, maybe if we had their names we could send them correspondence and hope that they'll read that it stresses the desirability of having their points of view presented and try to convince them that it is in their best interest to have someone here and speaking publicly. It is not easy, you're in a competitive field and there is a lot of secrecy.

Mr. Marx: I'm not in any position to speak for the tire companies but I can try though. When the call for papers goes out, if you direct some to me I will see what I can do to get some cooperation from the tire companies.

Comment: I think the point has to be made here that I am not too sure if I totally agree on the pressure not to attend. If there was pressure not to attend, we would not be here. As an industry we're "close to the chest" on what we tell our friends across town and so forth. It seems that Michelin has indicated that perhaps more than anybody in the industry, but I have to object to the pressure not to be here. I think the tire companies do very well in supporting the various societies. I think that point has to be made.

Comment: One of the gentlemen mentioned during his talk that he was disappointed about the turnout at the committee meetings. We were extremely disappointed in the fact that we were only able to attend one of these meetings. Some of us would like to attend most of the different group meetings but we can't do it because they're all held at the same time. I would have liked to attend two or three but I couldn't.

Mr. Merhib: We do have a restriction on time. I would like to open the floor to questions to see how to handle this sort of thing. We have a fixed amount of time and we have many committees. You just have to pick one, unless you extend the working group meetings over a long period of time, or change the whole format. For example, we could hold the working groups as we're holding them now but instead of only the reports would have full discussions of holography, then ultrasonics, then X-ray, then standards, etc., but you would extend your period of time into days, I'm sure. And we just don't have that sort of time.

Question: Do we need to hold these group meetings after the program, or can they be held during the program? Maybe one-half hour or forty-five minutes before lunch each day or maybe twice a day.

Mr. Merhib: You mean the working group meetings? No, they don't have to be held after the meetings, that is just the format that we have used three times before, and even with its drawbacks, there has been no strong objection.

Comment: I would like to make a suggestion that the first few days of the session, could the working meetings be held in the evenings? Most of us, I won't speak for all of us, but most of us spend our evenings looking at the tall end of the glass until about two in the morning. We could have as many as two sessions a night starting at the very first night because much of what is discussed in these working groups is stuff people have been thinking about before they came and does not always relate to the vendor type speeches that we hear anyways. And I would suggest that each evening we have two sessions. Say one starting out at about 7:30 and the other one at 9:30 so that everyone can attend. It was always a great deal of concern to me that I can't attend my competitors' sessions. I must be at my own. I would suggest that on the third evening, many of the people have already left, so that the very first few days, there be at least two or three sessions each evening and that we fill the evenings up with informal discussions and I would like to suggest that those discussions be closed door. In the optical society there are indeed locked door sessions. No members of the press are allowed and there is a general understanding amongst the members that are there that, that which they discuss is not carried out and discussed further. You would be rather surprised as to how well that is adhered to because, in the next session, the man who shoots off his mouth is not invited. And the people who really have an active contribution to it, as Carroll says, who really want to put a cookie into the jar, attend these sessions. It is unbelievable as to what is accomplished in the optical society meetings in the late hours. As a matter of fact on some occasions, until one or two in the morning. That is when the real donnybrooks take place. After holography was first invented, in that field and optics, I'll tell you there wasn't anyone of importance in the whole damn field who didn't attend that. You couldn't get standing room only, because everyone was so eager to hear what the other guy was going to say. At those times, everyone came—Dupont, Xerox, right down, IBM, RCA, and all the major universities, and

everyone who had two cents to put in was damn eager and in fact those were the sessions, which they really prodded people like Kodak. "What is your new film? What are you coming out with? The hell with using what you have got now. What do you have on the burner for next year?" "Where's the AGFA man? Get him in here," and they would start like that. These people, as compared to the tire industry, are not talking about individual compounding or specific constructions or specific test programs on the track but rather taking the situation of – well let's take Ed Pollard, in San Angelo. Ed, what have you used down there? What are you happy with? We don't need to know the specific details but how do you feel about this sort of thing. And let's get Glen Gray right up here beside him and I think you fellows might be a little surprised at how much could be gained from that *without* disclosing much of the confidential information. No one is more appreciative of the confidentiality than Hans Rottenkolber, Jim Thompson and myself. If you guys look in a dusty bar somewhere this week, most likely the three of us are together having a drink. We don't exchange circuit diagrams but we do exchange a lot of our feelings and I think in a way that we helped each other quite a bit. I think a lot could be done in this form without worrying about disclosing very much information because no one is more aware of the profit motive than guys like Jim or me. If he gets a little ahead of me on one circuit and I a little ahead of him on one, it's where the next machine sale is going. That's the same thing with you fellows on the tires. I think you have less danger –maybe more to lose than we have–but you have less danger than fellows like Jim or me. If Jim gets up a little earlier than me the next day there goes my next machine sale, and Hans Rottenkolber is breathing on us hot and heavy every day of the week and besides his time shift–his jet lag–is five hours, he's up five hours earlier than Jim or me. Now I would like you fellows to comment on that, as to whether there might be the kind of optical society meetings, the kind of ones in which you throw out people. It almost gets defensive in the beginning when you say who are you? Who are you with? You don't belong in this session. This is a private session and another guy comes in who has not been very active in the sessions in the past and as Carroll says, he hasn't put his cookie in the jar, so the hell with him too! so in these sessions much can be gained, and I think a more realistic perspective can be had. Are there any comments on that or anything?

Mr. Yeager: I go along with the idea about having night time evening committee meetings because things are changing. Five or six years ago, holography wasn't as well established, not as many studies, and I would have liked to have attended some of the other committees and I couldn't, I think the idea of having them in the evening would be great. Maybe two each evening for the first two evenings.

The other thing is the quality of the program. I have attended a lot of symposia on the west coast when I was working in the aircraft industry and also on the east coast. It seems like there is a tremendous difference. On the west coast, the attendees are much more critical. I don't mean to be sarcastic and facetious but they are more critical of the papers that are given; and, when they are critical of the paper, I think that if it is done on a constructive criticism, rather than just to knock somebody, I believe that you will enrich the symposium, you will make it a better quality. When you make it a better quality, you will get more people to attend. Keep it on a technical level, rather than political level. Sure, there will probably be some question on just what you can give, you don't give away the secrets. I really don't believe the secret stuff That I have never gone for. I think it is all ridiculous anyway. While I worked in the aircraft industry, just for example, just to show you something that is so ridiculous. They used to make us lock all our cabinets and put the secret bar on it. And when you unlocked it, you took the secret bar off and you put the lock on the inside and you closed the cabinet. And that was supposed to be safe. But when you left, somebody could walk in and replace that lock with their lock. You would lock that secret cabinet up at the end of the evening with their lock and they could come in that night and take anything they wanted out and put your lock back on. You would never even know anything was missing. This is how ridiculous I feel, that the secret thing can be carried and I think that if we become more critical of what type of papers are given and if we are more outspoken, and work together, I think there will be a more mutual trust between say the companies and the Government. There would be more open discussion; I think people would be in a more relaxed atmosphere. It's always been said that the Government only fills vacuum. If we create the vacuum then I think the Government rules will probably fall in. Let's say for example thirty or forty years ago would have been kind of ridiculous to try and design a supersonic transport. The state-of-the-art wasn't there and I think the state-of-the-art isn't there today to have the 100% inspection of any type of tire. We've tested probably, holography wise, pretty close to a million tires. We have a lot of information. I can't say too many things for sure. I'm not trying to hedge on it. I just don't know. I would ask anyone if they could say anything for sure in NDI. What a separation means exactly, how did it get there, and why. We can build certain types of tires that will do certain types of things but nobody builds bad tires on purpose. I think we should have more criticism to try to upgrade the quality of the meetings, don't be afraid to say something. If somebody gets up and says something that's off color or wrong, call them down on it. Then I think at the next meeting, you will have a better quality paper given and it will follow that with a better quality of paper you will have more attendees.

Mr. Merhib: Regarding the next symposium, please communicate your suggestions for a possible location to the time and place committee chairman Mr. Jack Price of Air Tread. Mr. Price is here I believe. So if you do want one and have any comments to make regarding another symposium Jack Price will be happy to accept those comments.

APPENDIX – ATTENDANCE ROSTER

4TH SYMPOSIUM OF NONDESTRUCTIVE TESTING OF TIRES

BUFFALO, N. Y.

SPONSORED BY
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

23-25 May 1978

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CONFERENCE SCENES

WORKING GROUP VIEWS. Center: Working Group Presenters; (Left to Right) Mr. Yeager, Standards; Mr. McConnell, Qualification; Mr. Merhib, Chairman; Dr. Grant, Holography; Mr. Kraska, Ultrasound; not shown, Mr. Greene, X-ray.

Left to Right Top: banquet headtable, Mr. Hampton, Mr. Yeager, Mr. Henry, COL Benoit, Mr. Lavery; COL Benoit, Mr. Fahey, Mr. Henry, Mr. Lavery; Mr. Merhib; Center: The Harmony Heroes; view of de-watered Niagara Falls as presented by Mr. Henry; Kathy Seege and Sue Coppella of the Executive Hotel assisted in planning the banquet and arrangements; Bottom: Mr. and Mrs. Price; banquet scene; Mr. Vogel.

Top to Bottom Left: Mr. Kyriakides, Dr. Grant, Mr. Hampton, Prof. Rottenkolber; Center: COL Benoit, symposium view, Prof. Clark; Right: Mr. Lavery, Mr. Klaasen, Mr. Lyngsgaard, Mr. Stiebel.

Top to Bottom Left: Mr. Yeager, Mr. Watts, Dr. Johnson, Mr. Zimmerman; Center: Mr. Neuhaus, symposium view, Mr. Bogdan; Right: Dr. Chait, Mr. Ritchie, Mr. Plank, Mr. Haskell.